NASA-CR-65158

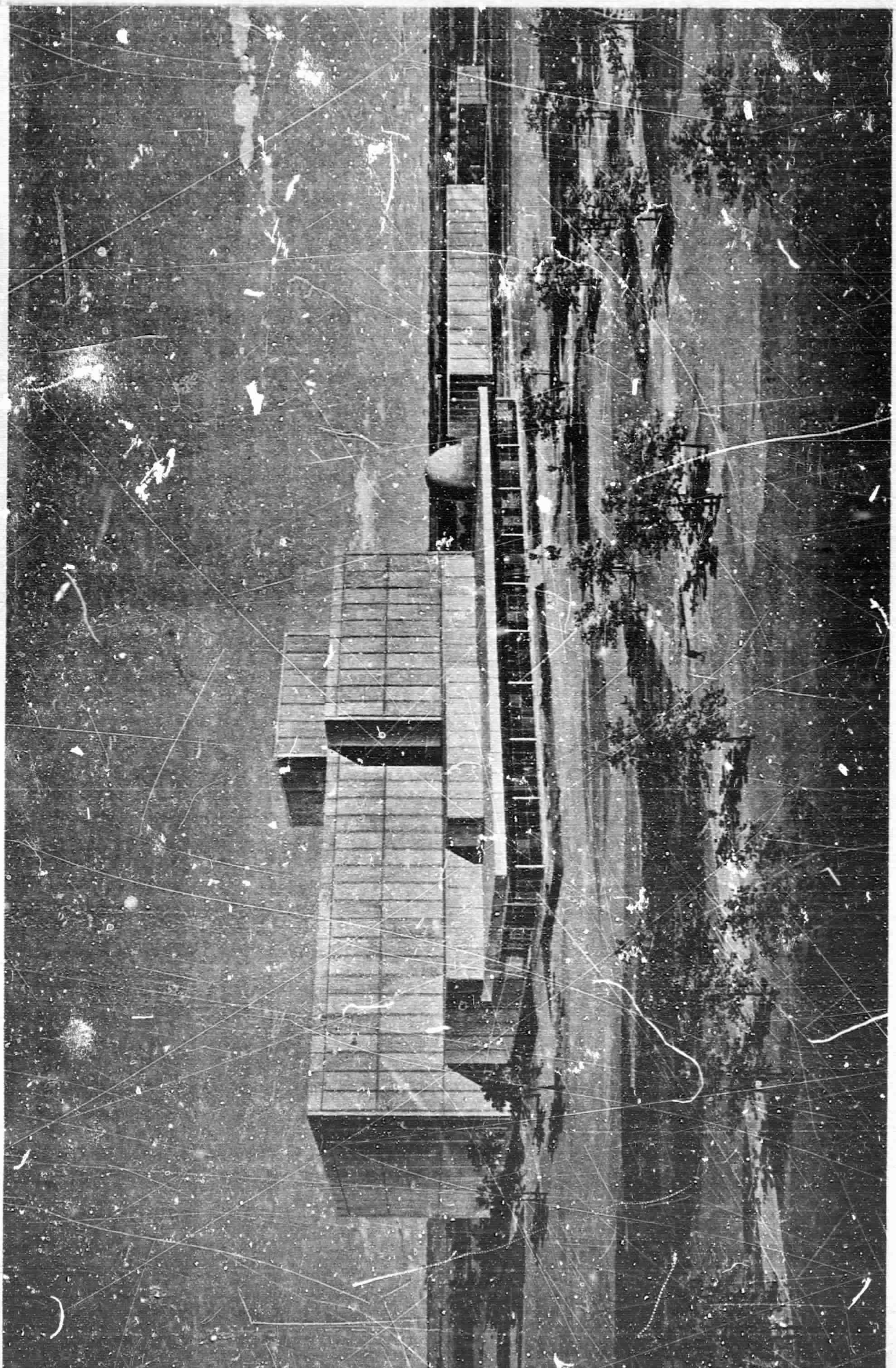
~~SPACE ENVIRONMENT CHAMBERS~~

FINAL REPORT

BECHTEL CORP.

JUNE 7, 1962 Contract - NAS 9-419

NAS 9-419



June 7, 1962

Mr. E. A. Gillam, Contracting Officer
Houston Petroleum Building
Manned Spacecraft Center
National Aeronautics and Space Administration
Houston, Texas

Dear Mr. Gillam:

Bechtel Corporation takes pleasure in transmitting herewith the final report required under terms of Contract No. NAS 9-419.

This study has proven to be a most challenging one in view of the scope of planning and engineering problems involved and the short time available for the study and report preparation. We believe the requirements of the study have been met and that the engineering design could proceed based upon the design criteria and conceptual facility design presented. It is our considered opinion that the cost estimate and schedule presented are attainable for the facility described by efficient prosecution of the work. Additional investigation beyond that possible during the study is necessary to establish the details of the schedule and the appropriate design packages. It must be recognized that any changes in concept of the facility or in the recommended project plan will necessarily involve adjustments in the cost estimate and schedule.

Bechtel Corporation and its associated companies wish to thank Manned Spacecraft Center for this opportunity to contribute to an extremely important NASA program. We look forward to continuing this work with Manned Spacecraft Center and other designated government agencies in the future.

Very truly yours,

W. Kenneth Davis

W. Kenneth Davis
Vice President

WKD:Pcg

FOREWORD

This report, consisting of three volumes, is submitted on work performed under a prime contract, No. NAS 9-419, let by Manned Spacecraft Center, National Aeronautics and Space Administration, to the Bechtel Corporation for studies and preliminary design of a Space Environment Chamber complex planned at the Manned Spacecraft Center, Houston, Texas. The three volumes are:

Vol. I	-	Summary
Vol. II	-	Studies and Recommendation
Vol. III	-	Design Criteria and Conceptual Design

The studies and design represent a 60-day effort by Bechtel Corporation and a team of the following industrial associates:

Air Products & Chemicals, Inc.	-	Cryogenics
Bausch & Lomb, Inc.	-	Radiation Simulation
Chicago Bridge & Iron Co.	-	Chamber Vessels
FMC Corporation	-	Special Mechanisms
General Electric Co. - MSVD	-	Data Handling & Man Rating
National Research Corp.	-	Vacuum

The objective of the study was to originate design criteria for a complex of space environment chambers which would most effectively and economically meet the MSC requirements for space environment testing within budget limitations. A project schedule and project cost estimate were also to be prepared. Work was conducted in close collaboration with the MSC Technical Coordination Staff and in accordance with technical guidelines issued by MSC.

Volume I presents a summary of the most important features of the final facility concept including Chambers A and B. Volume II presents studies and considerations made in defining the principal facility characteristics. Volume III presents the conceptual design generated, and the Design Criteria recommended for the engineering design phase.

Chamber D is not included in the final selected concept and no budget nor schedule provisions are made for it in the chamber complex presented herein.

Separate Design Criteria and conceptual design material presented on Chamber D is included so that in the future the necessary design, development and procurement phases of a Chamber D project might be undertaken in an expeditious way.

VOLUME 1 - SUMMARY

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SECTION I
SUMMARY DESCRIPTION

1.0 Location and Site - The Space Environment Simulation Chamber facility is located on the site of the Manned Spacecrafter Center, NASA, at Houston, Texas. The Chamber facility is one of a number of development and administrative facilities, which are integrated into and comprise the Center (See Frontispiece).

1.1 General Arrangement - The Chamber facility is composed of four major elements:

a. Chamber Building

b. Facility Administration Building

c. Refrigeration Building

d. Pump Building

The general arrangement of the facility is shown on the Plot Plan (Fig. I-1)

The Chamber Building (Fig. I-2, 3 & 4) is a high bay structure which houses the two man-rated Space Environment Simulation Chambers and related services and service areas. The larger of the two chambers, (65 ft diameter by 120 ft high) provides Space and Lunar Surface Environment Simulation while the smaller (35 ft diameter by 43 ft long) is a Space Chamber for Life Sciences and Astronaut Training Studies.

The Facility Administration Building (Fig. I-5) houses the facility offices, the biomedical services, and the control and test data handling areas.

It is located adjacent to the Center campus around which are located other Center facilities such as the Central Data Building, the Astronaut Training Unit, laboratories, and other development and administrative elements.

2.0 Space and Lunar Surface Environmental Chamber (Chamber A)

Chamber A is located at the north end of the Chamber Building. It is a vertical cylindrical stainless steel vessel, 65 ft in diameter and 120 ft high with a side access door 40 ft in diameter. While the initial use will be for manned test of complete Apollo spacecraft configurations, it can accommodate modular test vehicles up to 75 ft high, 25 ft in diameter with a 40 ft diameter base. A larger modular vehicle may be accommodated if certain test compromises can be accepted. The chamber is man-rated in its concept so that personnel in protective clothing can enter the chamber under test conditions to perform unscheduled maintenance or to simulate extra-vehicle manned operations in space. A floor in the chamber can be heated to simulate the lunar surface for vehicle and personnel tests. Man locks are located at several levels for personnel access. Provisions for personnel surveillance and rescue are incorporated in the design.

The Chamber A vacuum system provides an economical combination of mechanical, diffusion, and $20^{\circ}K$ ($-424^{\circ}F$) cryo-pumping capability sufficient for a test condition of 10^{-5} torr with a total gas load corresponding to twice that resulting from an Apollo spacecraft and two

space-suited personnel in the chamber. At this level of performance bake-out of the chamber prior to pumpdown is not required. Pumpdown from atmospheric pressure to the test condition is estimated to require 24 hours or less.

The interior of the chamber is lined with black, nitrogen-cooled heat sink panels at approximately 90°K (-298°F) to simulate the heat absorptive characteristic of space. Zoned temperature control is provided. To the maximum practical extent all surfaces in the chamber viewed by the test article consist of such heat sinks. Cryo pump surfaces cooled by gaseous helium are shielded from the test vehicle by heat sinks to minimize low temperature refrigeration requirements.

A turntable vehicle mount is provided suitable for rotating test vehicles up to 100,000 lbs in weight at rates up to 1-2/3 rpm about their longitudinal axes when vertically mounted. Hoists are provided in the top of the chamber to permit vehicle modules, introduced through the side door, to be assembled into a complete vehicle inside the chamber.

Solar simulators of modular design mounted external to the chamber on its side and top irradiate the test article through ports in the chamber wall. An intensity up to 140 watts per sq ft is available, corresponding to an earth orbit. Similar units are provided to simulate albedo heating.

3.0 Space Chamber for Life Sciences and Astronaut Training Studies (Chamber B) - Chamber B is located in the south end of the Chamber Building. It is a vertical stainless steel cylindrical vessel, 35 ft in diameter and 43 ft high. After removal of the vessel head, test articles are lowered into this chamber onto a fixed mount. The initial use of this chamber will be to carry out manned tests of the Apollo command capsule. The vessel can be modified to accept longer test articles by inserting a ten ft cylindrical extension below its head.

Man rating provisions are generally the same as for Chamber A. One double manlock for personnel access is provided. Surveillance and rescue provisions are similar. Capability for simulating a lunar plane is the same as in Chamber A.

The vacuum system for Chamber B provides mechanical and diffusion pump capability sufficint for a test condition of 10^{-4} torr with a total gas load corresponding to twice the leak rate from an Apollo command module and service module combination and two space-suited personnel in the chamber. Chamber back-out is not required. Pump-down from atmospheric pressure to the test condition is estimated to require 3 hours.

Heat sink provisions for Chamber B are the same as in Chamber A in concept and performance. No cryo-pump panels are employed.

A fixed mount suitable for supporting a 40,000 lb test vehicle is included in Chamber B. Design considerations have been made to permit expedient installation of a turntable mount similar to that in Chamber A at some future date.

A solar simulator module at the top of the chamber irradiates a test area of 25 sq ft from above only. Module characteristics and design are the same as those in Chamber A. No albedo heating is provided. Ports in the vessel for future installation of side solar simulator modules are provided.

4.0 <u>Space Chamber for Systems Test under Extreme Vacuum (Chamber D)</u> - Chamber D is not included in the facility due to current budget limitations. Its conceptual design provides for a vacuum level of 10^{-10} torr, empty, in a 6 ft diameter by 6 ft high vertical cylindrical test space with heat sink, solar radiation simulation, and various experimental appurtenances and penetrations. The outer vessel is about 11 ft in diameter and 17 ft high.

The concept of this chamber is that of a highly sophisticated research facility and requires technology which has not yet been demonstrated on a similar scale. A successful procurement project for such a chamber will necessarily involve substantial development in areas beyond the current state-of-art.

5.0 Refrigeration Plant - The cryogenic refrigeration plant primarily services the heat sinks of Chambers A and B, and the cryo-pumps of Chamber A. This plant, including storage and distribution facilities up to the chambers, is assumed to be a wholly-leased facility and no funds are allocated for its procurement in the accompanying facility cost estimates.

The nitrogen refrigeration plant provides 280 KW of rated capacity estimated to be adequate for the normal vehicle test condition. Peak loads with lunar plane in operation are provided for by a 100,000 gal liquid nitrogen storage facility which provides once-through cooling for the specified duration of the peak load.

The helium refrigerationplant provides 7.5 KW of rated capacity suitable for Chamber A requirements.

Upgrading of the solar simulator to accommodate larger target areas in Chambers A and B would require installation of additional nitrogen and helium refrigeration capacity. The cryogenic piping installed in the chambers is sized to accommodate the increased heat sink cooling requirements.

Addition of Chamber D to the facility would require installation of additional cryogenic refrigeration capacity, such as the 2.9 KW of 5^{o}K liquid helium refrigeration in the Chamber D conceptual design.

6.0 <u>Buildings</u> - The buildings of the chamber facility correspond in architectural treatment to others at the site according to the Master Plan. All of the buildings in the facility have structural steel frames with pre-cast concrete wall panels on the exterior.

The Chamber Building which encloses both Chambers A and B is approximately 266 ft long, 112 ft wide and 90 ft high. The lower half of the building is air-conditioned while the upper half is cross-ventilated. A 180 ft long crane runway is provided for the 50 ton bridge crane.

Foundations for the Chamber Building and the chambers within the building are on piles which penetrate approximately 60 ft of clay to reach the sand stratum.

The Facility Administration Building is approximately 200 ft long, 80 ft wide and two stories in height and is completely air-conditioned.

Administrative and biomedical offices on the ground floor have clear window-walls. Ceilings are acoustical tile with flush flourescent lighting fixtures. Interior partitions are standard moveable units with integrally designed door panel units and glass divider units.

The superstructure is a fire-proofed structural steel frame with siding of pre-cast concrete panels and window-walls. The roof is steel deck with light-weight concrete fill, rigid insulation and built-up roofing.

Foundations are drilled-and-underreamed caisson footings which bear on firm clay.

The Refrigeration Building is approximately 66 ft by 120 ft in plan and 30 ft high and houses the refrigeration compressors and associated service equipment, a control room and an office. A 10-ton bridge crane is provided for equipment maintenance. The office and control room are air-conditioned. The building foundations are drilled-and-underreamed caisson footings. Helium and nitrogen compressors are supported on piles.

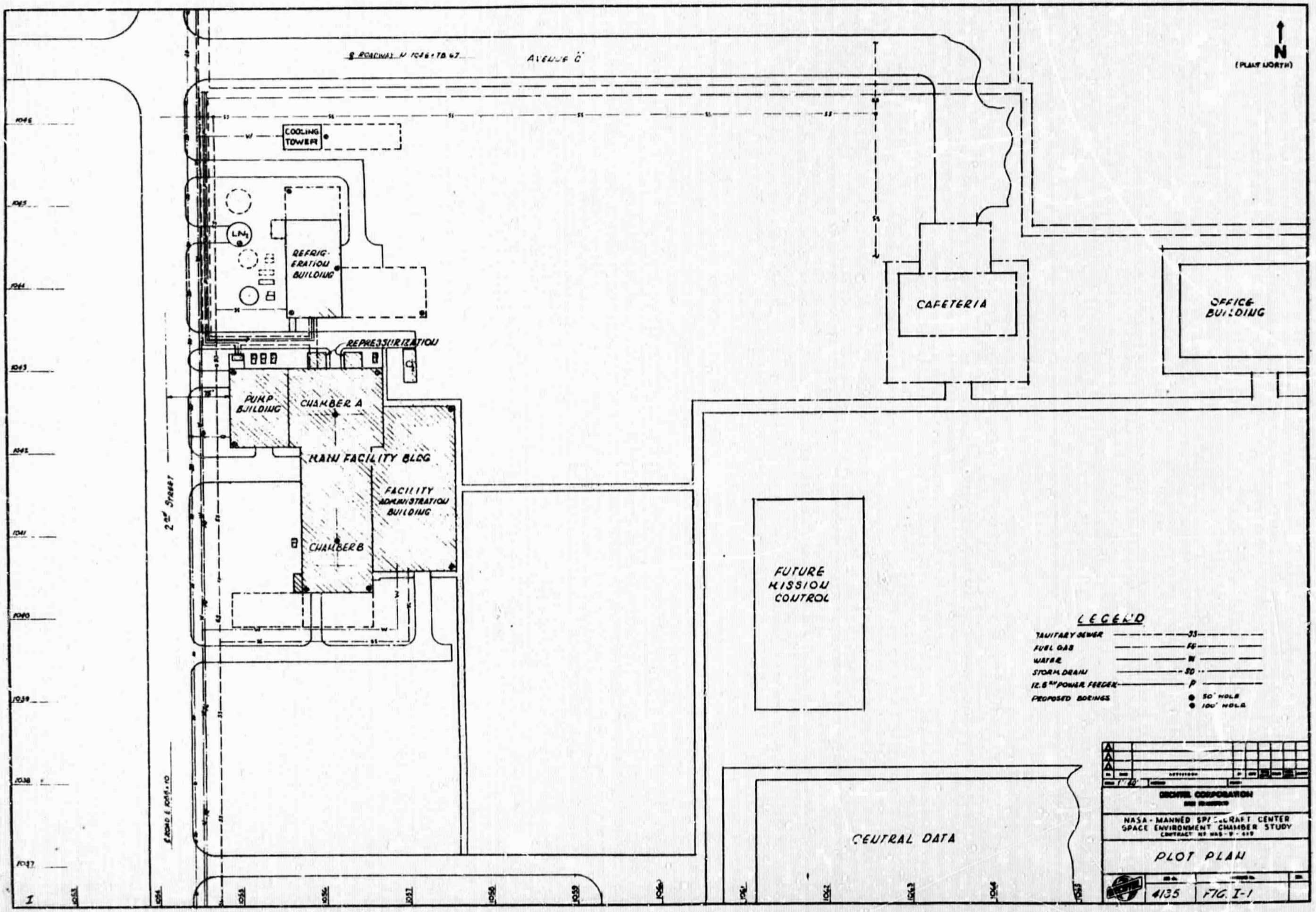
The Pump Building is approximately 72 ft by 90 ft in plane and 20 ft high. It is connected to the west side of the Chamber Building near Chamber A and encloses the roughing pump system, service water pumps, and air-compressors. The building foundations are drilled-and-underreamed caissons. The building is ventilated through wall intake fans and exhaust louvres. No air-conditioning is provided.

7.0 Facility Control and Instrumentation - Control of the facility is largely accomplished from two control boards located in the control room on the upper floor of the Facility Administration Building. The main control board for Chamber A is located at the north end of the room opposite Chamber A while that for Chamber B is at the south end of the room opposite Chamber B. This arrangement reduces the length of

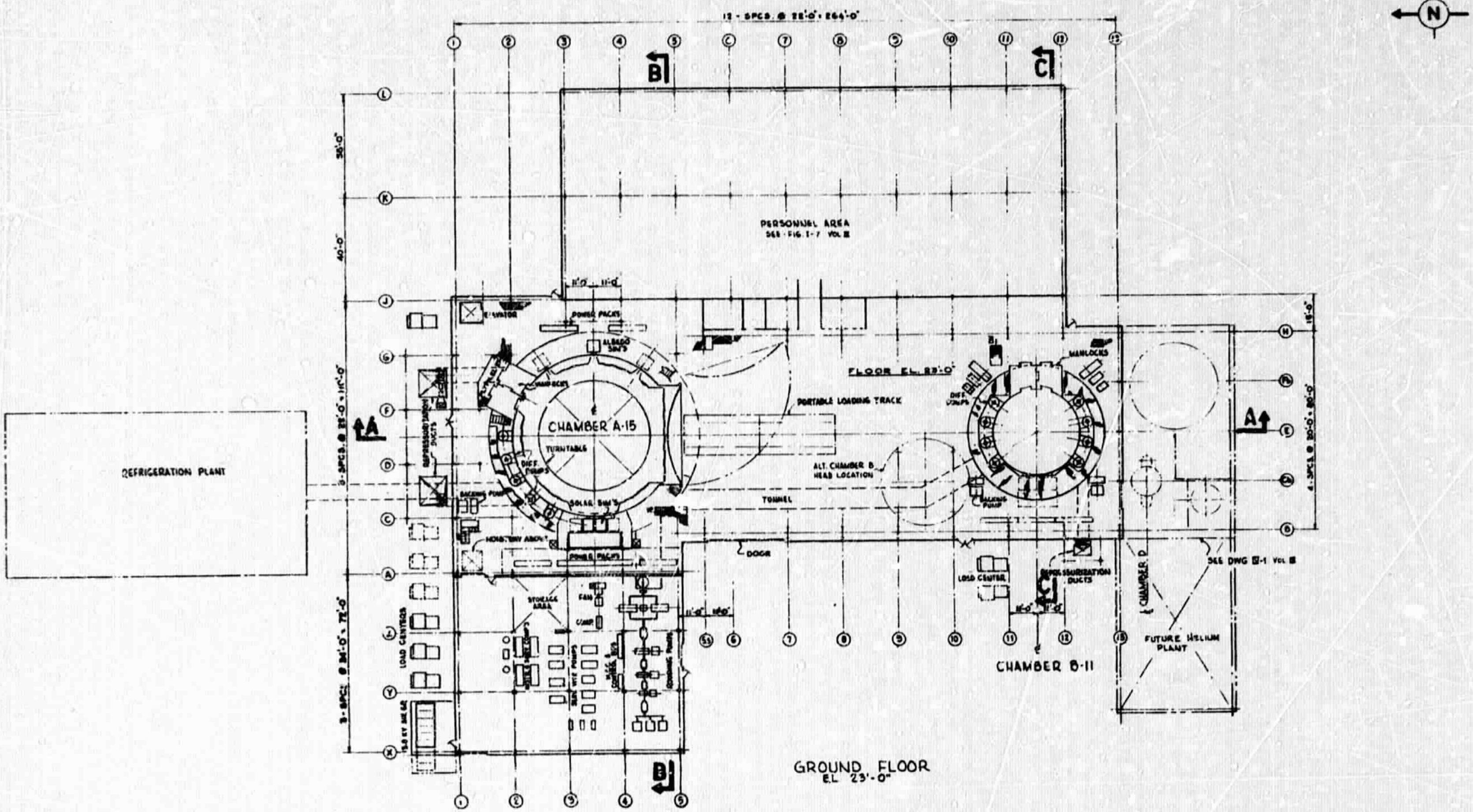
control piping and wiring. Each control board is located to form an integral component of the test data handling and biomedical surveillence area under the test conductor's direction. The main control boards are supplemented by local boards which provide an additional degree of control. These local boards for purposes of economy, are located in the Main Chamber Building adjacent to the system involved. The facility control is interconnected with the test article data handling system to furnish pertinent operating information for correlation with test data. Control and instrumentation is included for the vacuum system, cryogenic system,solar simulator, vehicle mount and lunar plane, repressurization system and the facility protective system.

8.0 Data Handling - A data handling system is provided to acquire and process data from the article under test and from astronauts in the chamber and in the facility. Wiring extends from the vehicle test mount through a junction box to patch panels at the control room, thence to the data handling equipment. A console in the control room provides supervisory data for the test conductor and the biomedical monitors. A leased digital process computer is the central unit of the data handling system serving both Chamber A and Chamber B test areas concurrently. Space is provided in the control room for equipment for special test article sub system checkout as the need arises.

9.0 <u>Man-Rating</u> - Provision is made for personnel to enter each chamber in suitable protective clothing. For ingress and egress to the chamber under test, man locks are provided. In Chamber A elevated balconies are provided to allow circulation and upper-level access to test vehicles. An emergency repressurization system is provided for each chamber for rescue of personnel who are exposed to the vacuum environment due to the loss of space suit pressure. The condition of personnel in the chamber is monitored on the biomedical console in the control room. TV coverage and view ports are provided in the chamber and locks. Medical personnel and facilities are housed in the adjacent Facility Administration Building as is the space for astronaut dressing, taping, suiting and denitrogenization.



N
(PLANT NORTH)
AVENUE C
COOLING TOWER
LN_2
REFRIGERATION BUILDING
REPRESSURIZATION
PUMP BUILDING
CHAMBER A
MAIN FACILITY BLDG
FACILITY ADMINISTRATION BUILDING
CHAMBER B
2nd STREET
CAFETERIA
OFFICE BUILDING
FUTURE MISSION CONTROL
CENTRAL DATA
LEGEND
SANITARY SEWER — SS
FUEL GAS — FG
WATER — W
STORM DRAIN — SD
12.5 KV POWER FEEDER — P
PROPOSED BORINGS
50' HOLE
100' HOLE
BECHTEL CORPORATION
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
PLOT PLAN
4135
FIG. I-1



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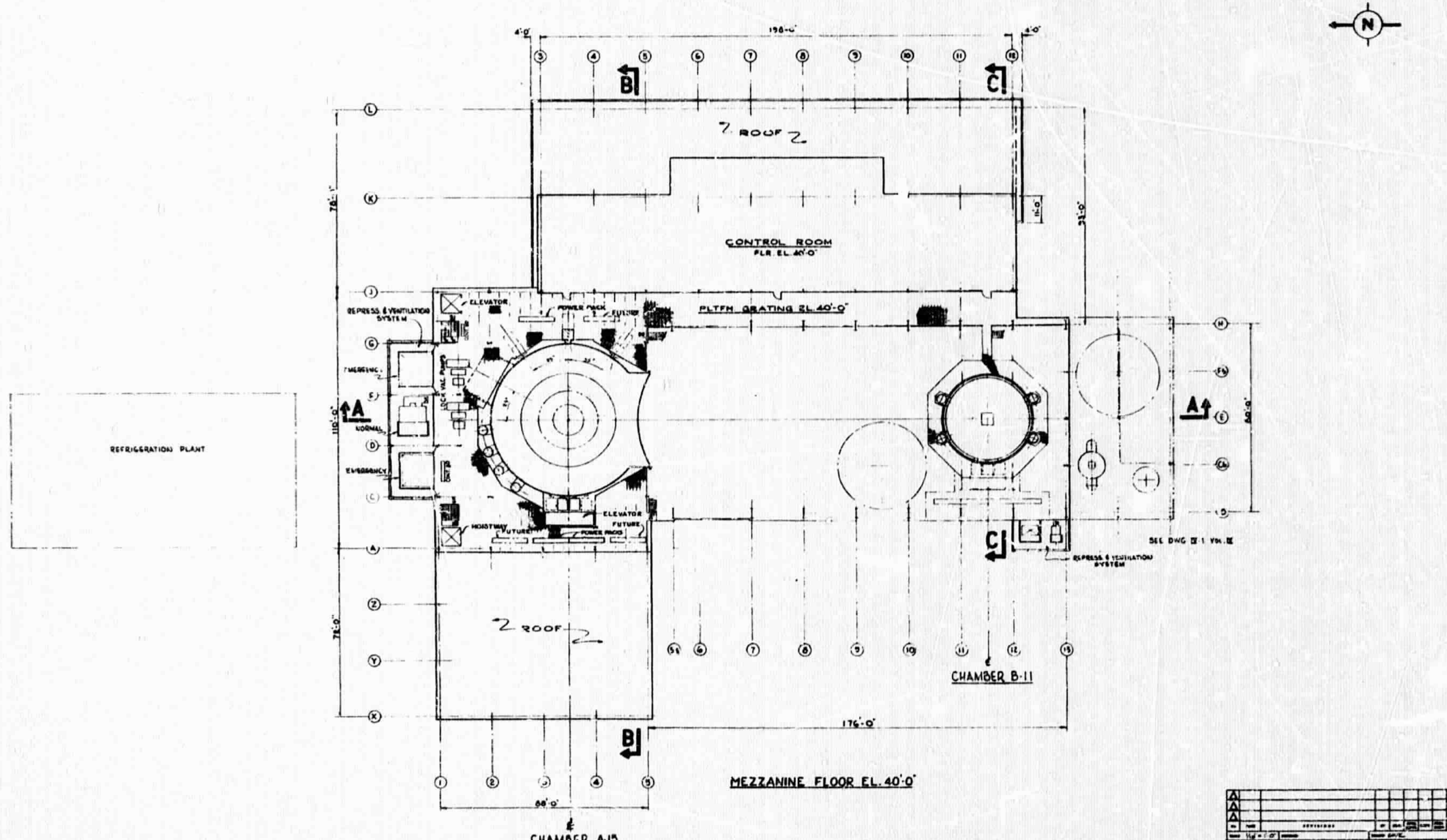
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

GENERAL ARRANGEMENT
CHAMBERS "A" & "B"
GROUND FLOOR PLAN

4189 | FIG. I-2

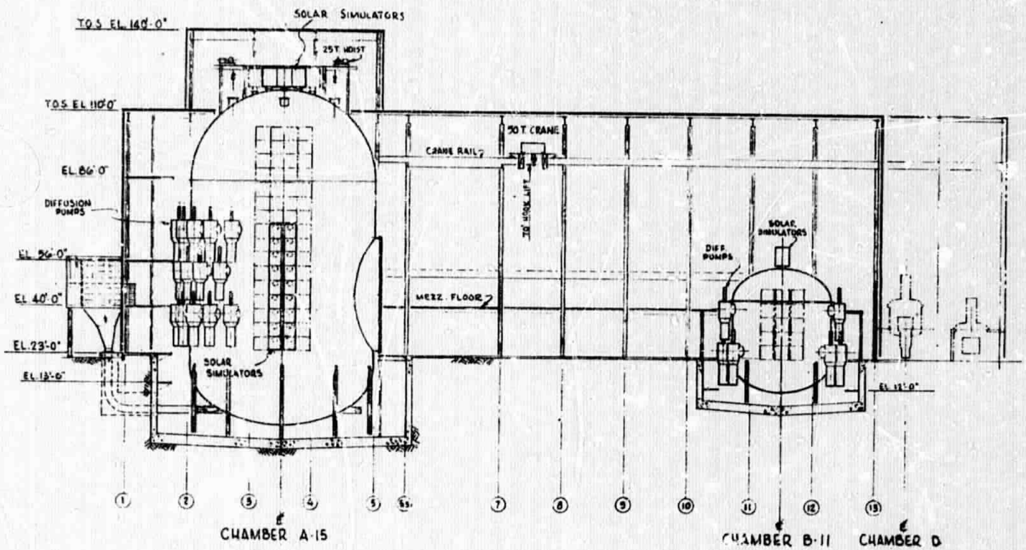


BECHTEL CORPORATION
SAN FRANCISCO

NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

GEN. ARRGT.
PLAN AT MEZZANINE FLOOR

4185 FIG I-3



SECTION A-A

SCALE: 1/16" = 1'-0"

SCALE IN FEET

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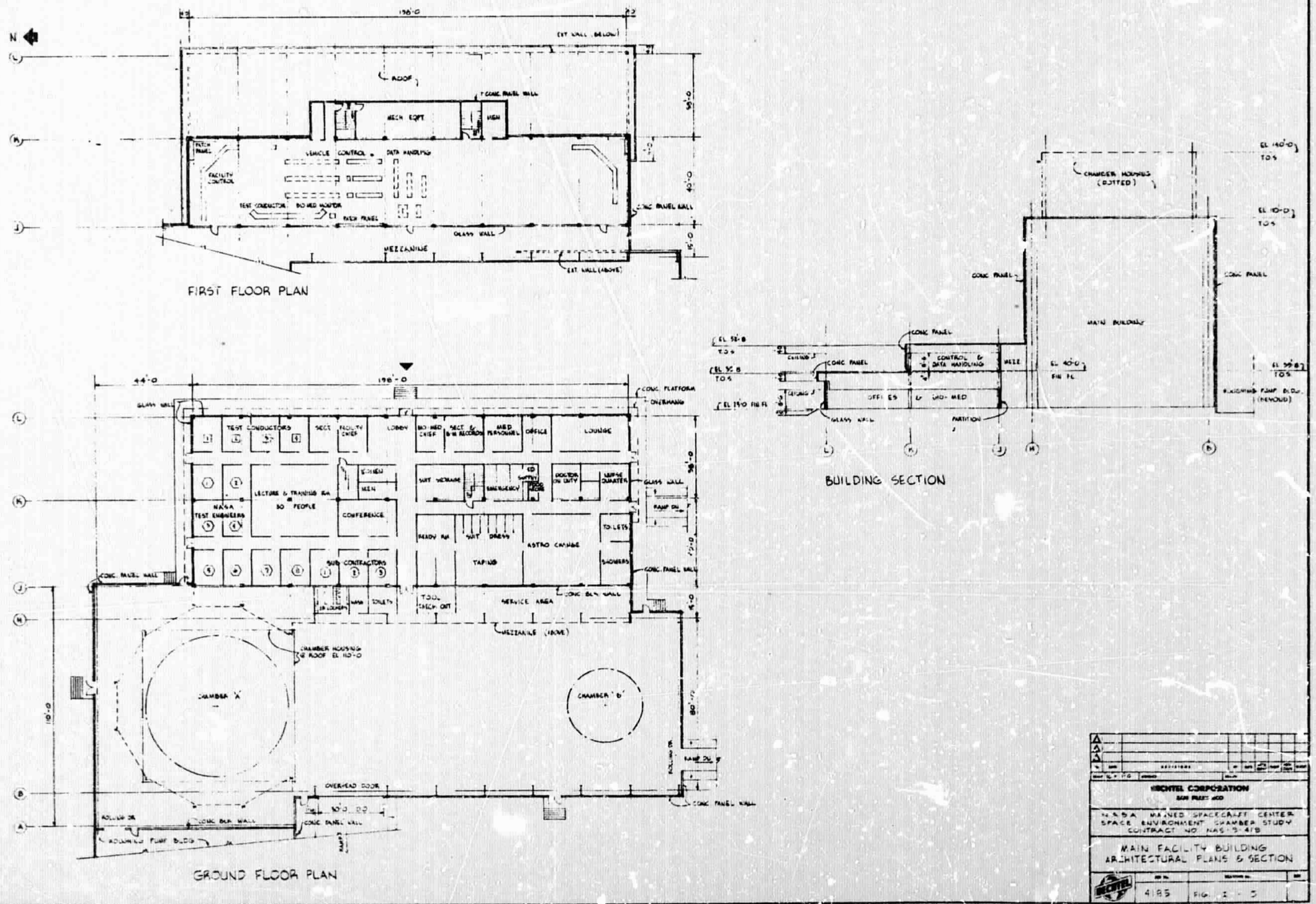
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

GENERAL ARRANGEMENT

SECTION A-A

4185 FIG. I-4

I


FIRST FLOOR PLAN
ROOF
MECH EQPT
VEHICLE CONTROL
DATA HANDLING
FACILITY CONTROL
TEST CONDUCTOR
BIO MED MONITOR
PATCH PANEL
GLASS WALL
MEZZANINE
CONC PANEL WALL
EXT WALL (BELOW)
EXT WALL (ABOVE)
196'-0
BUILDING SECTION
CHAMBER HOUSING (DOTTED)
MAIN BUILDING
CONTROL & DATA HANDLING
OFFICES
BIO-MED
CONC PANEL
GLASS WALL
PARTITION
EL 140'-0 T.O.S
EL 110'-0 T.O.S
EL 40'-0 FIN FL
GROUND FLOOR PLAN
TEST CONDUCTORS
SECT
FACILITY CHIEF
LOBBY
BIO MED CHIEF
SECT & B-M RECORDS
MED PERSONNEL
OFFICE
LOUNGE
LECTURE & TRAINING RM 50 PEOPLE
NASA TEST ENGINEERS
CONFERENCE
SUIT STORAGE
EMERGENCY
DOCTOR ON DUTY
SLEEPING QUARTER
READY RM
SUIT DRESS
ASTRO CHANGE
TAPING
TOILETS
SHOWERS
SUB CONTRACTORS
TOOL CHECK OUT
SERVICE AREA
MEZZANINE (ABOVE)
CHAMBER HOUSING ROOF EL 110'-0
CHAMBER 'A'
CHAMBER 'B'
OVERHEAD DOOR
CONC PANEL WALL
CONC BLK WALL
CONC PLATFORM OVERHANG
BECHTEL CORPORATION
SAN FRANCISCO
N.A.S.A. MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NO NAS-9-418
MAIN FACILITY BUILDING
ARCHITECTURAL PLANS & SECTION
4185
FIG. I - 5

I

SECTION II

COST ESTIMATE

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INTRODUCTION

1.0 Scope - These cost estimates are based on Design Criteria and Conceptual Design for a Space Environmental Chamber Complex and a planned Chamber D facility at the Manned Spacecraft Center, Houston, Texas, as described in Volume III of this report.

Essentially the Complex for these study purposes consists of two test chambers (A and B), vacuum pumping, solar simulation, refrigeration plant and cryogenic system, Facility Administration and Equipment Buildings, control and instrumentation, data handling, site facilities inside a designated area and power distribution for the complete facility. The scope of the follow-on design and construction project is expected to be further limited.

The cost estimate of the Complex is divided into two major parts; they are (1) Government Owned Facilities consisting primarily of Chamber A and Chamber B and certain facilities and services common to both; and (2) Government Leased Facilities consisting of the refrigeration system and the data handling equipment.

2.0 Estimate Definition and Description - The principal estimate is a Preliminary Construction Cost Estimate for the Complex and includes costs for construction materials, erection labor, subcontracts,

an allowance for all other contractor costs including overhead and profit, and a construction contingency. A separate allowance for Abnormal Design Costs is also included.

Charges of Government Agencies for administration and supervision of the project, together with normal engineering and design costs, and land costs are not included in the Cost Estimate.

The cost estimate for Chamber D is a preliminary estimate excluding development based on conceptual design as described in Volume III.

3.0 Basis of Preliminary Construction Cost Estimate For Complex

The estimate is based on construction practices which are consistent with key dates of the recommended construction schedule. The schedule is based on a normal 40 hour work week, making allowance for spot overtime except for Chamber A and Chamber B vessel fabrication and erection which is scheduled on a two-shift basis.

This cost estimate is based on material and equipment prices, labor rates, and labor benefits and prices at June 1, 1962.

Cost for Government Leased Facilities are vendor estimated procurement costs for these facilities.

4.0 <u>Principal Equipment Exclusions from Preliminary Construction Cost Estimate</u> - Major exclusions include:

1. T. V. Cameras and Monitors
2. Office Furniture and Equipment
3. Medical Furniture and Equipment including space suits, umbilical systems, etc.
4. Operating Supplies: Nitrogen, Oxygen, Helium, Diffusion pump oil, lubricants, etc.
5. Dollies for Module Handling
6. Shop tools and equipment
7. Six lamps for each module (only one lamp per module included)
8. All other portable equipment
9. All leased facilities

PRELIMINARY CONSTRUCTION COST ESTIMATE

ESTIMATE SUMMARY

CHAMBER A & CHAMBER B COMPLEX

GOVERNMENT OWNED FACILITIES

I	LAND ACQUISITION		None Included
II	SITE DEVELOPMENT & UTILITY DISTRIBUTION	$	800,000
III	FACILITIES ("BRICK & MORTAR")		3,000,000
IV	EQUIPMENT, INSTRUMENTATION, AND SUPPORT SYSTEMS		14,250,000
V	ABNORMAL DESIGN COSTS		1,250,000
	TOTAL (EXCLUDING NORMAL DESIGN)	$	19,300,000

GOVERNMENT LEASED FACILITIES

Vendors Estimated Cost for Outright Purchase of these Facilities

I	REFRIGERATION	$	4,800 000
II	DATA HANDLING EQUIPMENT (COMPUTER SYSTEM)	$	600,000

CHAMBER D-FACILITY

I	CHAMBER D - PRELIMINARY ESTIMATE EXCLUDING DEVELOPMENT		
	5^{o}K HELIUM REFRIGERATION	$	3,200,000
	20^{o}K HELIUM REFRIGERATION	$	2,100,000

PRELIMINARY CONSTRUCTION COST ESTIMATE

CATEGORY SUMMARY

GOVERNMENT OWNED FACILITIES

				Total Cost
I	LAND ACQUISITIONS			None Included
II	SITE DEVELOPMENT			
	1.	GRADING	$	39,000
	2.	ROADS, PARKING AREAS & PAVING		35,000
	3.	EROSION CONTROL		10,000
	4.	UTILITY & SERVICE TUNNELS		144,000
	5.	SANITARY & STORM SEWERS		36,000
	6.	FIRE WATER SYSTEM		5,000
	7.	AREA LIGHTING		25,000
	8.	UTILITY DISTRIBUTION		506,000
		TOTAL - SITE DEVELOPMENT	$	800,000
III	FACILITIES ("BRICK & MORTAR")			
	1.	MAIN FACILITY BUILDING		
		A. CHAMBER BUILDING	$	2,025,000
		B. ADMINISTRATION BUILDING		875,000
	2.	PUMP BUILDING		100,000
		TOTAL - FACILITIES	$	3,000,000

		Total Cost
IV	**EQUIPMENT, INSTRUMENTATION & SUPPORT SYSTEMS**	
	1. CHAMBER A - SPACE SIMULATOR	
	A. CHAMBER A	$ 3,123,000
	B. SOLAR & ALBEDO SIMULATION	1,805,000
	C. CRYOGENIC SYSTEM & LUNAR PLANE	2,600,000
	D. INSTRUMENTS & CONTROLS	1,207,000
	E. DATA HANDLING (LESS LEASED EQUIPMENT)	317,000
	F. BIOMEDICAL FACILITIES	60,000
	G. SPECIAL HANDLING SYSTEMS	178,000
	H. PUMPING SYSTEMS - VACUUM, WATER & AIR	1,100,000
	I. CHAMBER REPRESSURIZATION (NORMAL & EMERGENCY)	290,000
	J. ELECTRICAL POWER	190,000
	K. ACCEPTANCE TESTS	300,000
	TOTAL - CHAMBER A	$ 11,170,000
	2. CHAMBER B - SPACE SIMULATOR	
	A. CHAMBER B	$ 950,000
	B. SOLAR SIMULATION	60,000
	C. CRYOGENIC SYSTEM & LUNAR PLANE	435,000
	D. INSTRUMENTS & CONTROLS	586,000
	E. DATA HANDLING (LESS LEASED EQUIPMENT)	270,000
	F. BIOMEDICAL FACILITIES	35,000
	G. SPECIAL HANDLING SYSTEMS	48,000
	H. PUMPING SYSTEMS - VACUUM, WATER & AIR	383,000
	I. CHAMBER REPRESSURIZATION (NORMAL & EMERGENCY)	153,000
	J. ELECTRICAL DISTRIBUTION AND SERVICE	60,000
	K. ACCEPTANCE TESTS	100,000
	TOTAL - CHAMBER B	$ 3,080,000
	TOTAL CHAMBERS A & B COMPLEX	$ 14,250,000

V. ABNORMAL DESIGN COSTS

		Total Cost
1.	FOUNDATION STUDIES	$ 25,000
2.	EXTRAORDINARY DESIGN	600,000
3.	EXTRAORDINARY CONSULTING SERVICE	50,000
4.	CONSTRUCTION CONTRACT CHANGES	90,000
5.	REVIEW SHOP DRAWINGS	60,000
6.	MONITORING ACCEPTANCE TESTS	50,000
7.	MAINTENANCE & OPERATING MANUALS	275,000
8.	TROUBLE SHOOTING	30,000
9.	COST OF TRAINING GOVERNMENT	
10.	PERSONNEL	40,000
11.	SAFETY CONSIDERATIONS	30,000
	TOTAL - ABNORMAL DESIGN COSTS	$ 1,250,000
	TOTAL (EXCLUDING NORMAL DESIGN)	$ 19,300,000

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
I LAND ACQUISITIONS		NONE	INCLUDED	
II SITE DEVELOPMENT & UTILITY INSTALLATION				
1. GRADING				
Clear and Rough Grade	10 acres	$ 400.00	$ 4,000	Includes stripping and removal of sod from area
Finish Grading & Terracing Lot			35,000	Includes fill and compaction of terrace around facility and finish grade of area.
		SUB TOTAL	$ 39,000	
2. ROADS, PARKING AREAS & PAVING				
Roads:				
Reinforced Concrete 6 inch	1,500 sy	10.00	$ 15,000	Includes sub base and drainage
Concrete Stairs Outside Administration Building	100 cy	100.00	10,000	Includes earthwork
Sidewalks 3 inch thick	18,000 sf	.45	8,000	Includes earthwork
Storage Pad - West Side Chamber Building	2,000 sf	1.00	2,000	Includes earthwork, sub-base, reinforcing and drainage
		SUB TOTAL	$ 35,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
3. EROSION CONTROL	1 Lot	$ -	$ 10,000	Sprigging of finished construction area. No plantings or landscaping included.
4. UTILITY & SERVICE TUNNELS				Service Tunnel connects with existing tunnels at approx. Plant coordinates N-1046/25 and E-1054/60
Excavation and Backfill	6,000 cy	5.00	33,000	Includes excavation, compacted backfill, dewatering shoring & protection of existing underground utilities.
Concrete Tunnel	500 lf	190.00	95,000	Includes forming, reinforcing, waterproofing, misc. inserts, concrete and pouring. Approx. 700 cy Tunnel 8' wide by 8 ' high
Tunnel Drain System	550 lf	11.00	6,000	Includes Sump Pumps, Piping & Electric
Tunnel Lighting System	1 Lot		10,000	Vapor Tight Fixtures
	SUB TOTAL		$ 144,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
5. SANITARY & STORM SEWERS				
Sanitary Sewers:				
8 inch Cast Iron	500 lf	$ 11.00	$ 5,500	Includes excavation and backfill
Storm Sewers:				
12 inch VCP	1,850 lf	12.50	23,000	Includes excavation and backfill. Approx depth 13 feet
Fittings, Flanges etc.	1 Lot		3,000	
Manholes	6 ea	750.00	4,500	Complete including excavation, concrete, forms, resteel, manhole covers, etc.
		SUB TOTAL	$ 36,000	
6. FIRE WATER SYSTEM	allowance		$ 5,000	
7. AREA LIGHTING				
Light Fixtures	30 ea	--	25,000	
Conduit	1800 lf			
Standards	15 ea			
Concrete Encasement	30 cy			
		SUB TOTAL	$ 25,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
8. UTILITY DISTRIBUTION				
Piping:				
Steam Lines-4" insulated	600 lf	$ 12.50	$ 7,500	Includes insulation and steam control valves, hangers and supports
Condensate Lines - 2 1/2" insulated	600 lf	9.20	5,500	Includes insulation
Potable Water - 2 inch	500 lf	8.00	4,000	
Chilled Water - 39^o (Supply and Return)	--	--	--	Included with Air Conditioning System
Supports & Hangers (In Tunnel)	--	--	--	Included with Tunnel Piping
Electrical Feeders and Substations				
Main Breakers & Feeders for Main Facility	1 Lot	--	134,000	Includes main circuit breakers and (2) feeders from main substation to facility
Concrete Pads	50 cy	100.00	5,000	Includes excavation, back-fill, forming, reinforcing, inserts, concrete, pouring and finishing

	DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
8	UTILITY DISTRIBUTION (cont'd)				
	Refrigeration Plant	1 Lot	--	$ 104,000	Includes main circuit breakers and (2) feeders from main substation to Refrigeration Plant
	Electrical Substation	Lump Sum	--	170,000	Includes 13.8 KV switchgear, 480 V switchgear, and main transformer bank for Chamber Facility only - switchgear for Refrigeration Plant is included with the leased Refrigeration Plant.
	Grounding	1 Lot	--	26,000	
	Communications	4000 lf	2.50	50,000	
		SUB TOTAL		$ 506,000	
	TOTAL - SITE DEVELOPMENT			$ 800,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
III FACILITIES (Brick & Mortar)		$	$	
1. MAIN FACILITY BUILDING				
A. Chamber Building				
Volume	2,270,000	0.89/cf	--	
Floor Area (ground)	25,200	--	--	
Foundation:				
Earthwork	4,350 cy	7.80	34,000	Includes 1850 cy of excavation and 2500 cy selected compacted sand backfill
Concrete	975 cy	95.00	92,500	Includes column footing, perimeter wall and floor slab with membrane moisture proofing.
Piling	9,200 lf	10.00	92,000	Step-tapered, poured in place
Tunnels inside building:				For repressurization lines and other services to chambers (8' wide x 11'high)
Earthwork	5,000 cy	7.00	35,000	Includes excavation, compacted backfill, dewatering, and shoring.
Waterproofing	23,000 sf	.60	14,000	
Concrete	520 lf	290.00	150,000	Includes forming, reinforcing, misc. inserts, concrete and paving. Approx. 770 cy

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
A. Chamber Building (Cont'd)				
Drainage	1 Lot	--	$ 6,000	Includes sumps, pumps and piping
Deadmen & Foundations for Guy Derrick	235 cy	100.00	23,500	For erection of Chamber A Includes excavation, concrete and reinforcing.
Structural Steel	900 T	510.00	459,000	Includes building steel, platforms, walkways, stairways, handrail, and misc steel in building and around Chambers A and B
Aluminum Grating	3,100 sf	6.25	19,500	
Steel Grating	28,400 sf	3.50	100,000	
Siding (Special)	58,000 sf	4.40	254,500	Precast mosaic with interior insulation and plaster
Roof	25,200 sf	1.40	35,000	Includes metal deck, rigid insulation, built-up tar and gravel roof, and flashing
Lift Door (30'w x 39'H)	1 ea	--	20,000	
Other Doors	6 ea	--	2,000	Includes 5 man doors and (1) truck door

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
A. Chamber Building (Cont'd)				
Interior Finish:				
Painting Steel	900 T	$ 20.00	$ 18,000	Structural and Misc steel
Walls	83,000 sf	.10	8,000	Walls and Roof
Building Services:				
Plumbing & Utilities	Lot	0.035/cf	75,000	
Heat. Vent & A.C.	Lot	.095/cf	205,000	Air Cond. - 295T
Power & Control	Lot	- -	76,000	
Lighting	Lot	- -	85,000	
Building Equipment:				
Bridge Crane				
50 T x 80' span	1 ea	- -	121,000	
Service & Personnel Elevator	1 ea	- -	35,000	
Vehicle Handling Hoists	4 ea	- -	65,000	
	SUB TOTAL		$ 2,025,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
B. Facility Administration Building		$	$	
Volume	402,000 cf	- -	- -	
Floor Area	25,130 sf	34.80/sf	- -	
Foundation:				
Earthwork	2,700 cy	8.00	21,600	Includes 2500 cy selected compacted sand backfill
Concrete	360 cy	86.00	31,000	Includes perimeter walls and slab or grade with membrane moisture proofing.
Piling(Drilled Caisson)	600 cy	62.00	37,000	Includes bell bottom caisson, reinforcing, conc. and pouring.
Structural Steel 210 T Str. Steel 25 Misc. Steel	235 T	470.00	110,000	
Fireproof Struct. Steel	1 Lot	- -	35,000	2 hour fire protection
Siding (Special)	7,200 sf	4.40	32,000	Including insulation and plaster
Exterior Glass Wall	3,900 sf	5.50	21,500	Including main entrance doors.

	DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
B	Facility Administration Building (Cont'd)				
	Interior Finish:				
	Conc. Floor Slab	10,400 sf	$ 1.40	$ 14,500	Floor slab for second floor control room
	All Interior Finish	Lot	0.50/cf	200,000	Includes ceiling, partitions, floor coverings, ducts, painting, etc.
	Roof	18,100 sf	1.60	29,000	Includes concrete slab under roofing on office area for future extension of second floor control room (8,000 sf) and metal roof deck, rigid insulation, tar and gravel built up roof for entire building
	Common Wall w/Main Facility Building	5,100 sf	1.80	9,400	Concrete block & glass
	Building Services:				
	Plumbing & Utilities	Lot	1.25/cf	50,000	
	Heat. Vent. & A. C.	Lot	.52/cf	210,000	Includes 275 T A. C.
	Power & Lighting, Lighting & Cableway	Lot	- -	74,000	
		SUB TOTAL		$ 875,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
2. **PUMP BUILDING**		$	$	
Volume	101, 500 cf			
Floor Area	6, 600 sf	15.00/cf		
Foundation:				
Earthwork	650 cy	8.25	7,000	Includes 800 cy selected compacted sand backfill
Concrete	125 cy	84.00	10, 500	Includes perimeter and slab on grade, with membrane waterproofing, and reinforced to support mechanical equip.
Piling (Drilled Caisson)	225 cy	65.00	14, 600	Includes bell bottom caissons, reinforcing, concrete and pouring.
Structural Steel and Misc. Iron	32 T	500.00	16, 000	
Siding (Special)	3, 800 sf	3. 70	14, 000	
Interior Finish:				
Painting	---	---	2, 500	
Roof	6, 600 sf	1. 40	9, 300	Includes metal deck, insulation and tar and gravel built up roof

DESCRIPTION	QUAN.	UNIT COST	TOTAL COST	REMARKS
2. PUMP BUILDING (Cont'd)		$	$	
Doors & Hardware				
12' x 14' equip. and service doors		--	2,500	
Walk-in Main Door		--		
Building Services:				
Plumbing & Services		0.07/cf	7,000	
Heat. & Ventilate		0.07/cf	7,000	Air Conditioning has not been provided for this Building
Power & Lighting	[illegible] sf	1.45	9,600	
		SUB TOTAL	$ 100,000	

IV EQUIPMENT, INSTRUMENTATION & SUPPORT SYSTEMS

DESCRIPTION	QUAN.	UNIT COST	TOTAL COST	REMARKS
1. CHAMBER A - SPACE SIMULATOR				
A. Chamber A				
Foundation:				
Earthwork	10,000 cy	5.70	57,000	Includes 8500 cy of excavation and 1500 cy selected compacted sand backfill, shoring and dewatering
Concrete	1,620 cy	105.00	170,000	Includes forming, reinforcing, waterproofing, imbedded metal, concrete and pouring

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
		$	$	
A. Chamber A (Cont'd)				
Piling:	4,650 lf	11.00	51,000	Step tapered poured in place
Drain System	Lot	- -	4,000	Vessel A Fdn Pit - Sump Pump Included
Chamber Vessel, Complete including the following:	1 ea	- -	2,523,000	(1) 65 ft Ø by 120 ft overall Stainless shell with Carbon Steel Stiffeners & C. S. Man-locks. (2) Vessel Interior Surface - Mill finish only - not polished
a. 40'Ø Main Entrance Door and O-ring seals	1 ea			
b. Struct. Platforms Inside Chamber	2 ea			
c. Penetrations:				
Vacuum Pumps - 48"Ø	14 ea			
Solar Simulators - 18"Ø	32 ea			
Future Solar Simulators - 18" Ø	64 ea			
Repressurization Ports - 48" Ø	4 ea			
Viewing Ports	allowance			
Nitrogen & Helium Supply and Return Lines	allowance			
Vehicle Handling Hoists - 48" Ø	4 ea			

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
A. Chamber A (cont'd)		$	$	
d) 4' x 7' Man-access Door & Weld Ring for Future Man Lock	1 ea			
e) Support for Rotating Table	allowance			
f) Personnel Locks (Carbon Steel)				
Single Man Lock	1 ea			
Double Man Lock	1 ea			
g) Clean & Test				
Vessel Fabrication Premium			125,000	Premium Cost for Double Shift-work-on Vessel fabrication and erection. Necessary to advance completion of vessel.
Handling Apparatus for 40 'Ø Entry Door	Lot	--	190,000	
Thermal Insulation		NONE REQUIRED		
Painting	allowance	--	3,000	Carbon Steel Supports & Man Locks - S.S. Portion will not be painte .
	SUB TOTAL		$ 3,123,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
B. Solar & Albedo Simulation		$	$	
Simulator Modules:				
Side Sun	18 ea	--		Includes one (1) lamp only for each simulator module
Top Sun	4 ea	--	1, 710, 000	
Albedo	9 ea	--		
Simulator Housing	Lot	--	20, 000	
Structural Steel Supports for Solar Simulators	Lot	--	15, 000	
Module Service Elevator	2 ea	--	60, 000	
Electric Power:				Electrical work for solar simulator is included in Item J (a)
Solar Simulators	--	--	--	
Lunar Plane		--		
	SUB TOTAL		$ 1, 805, 000	
C. Cryogenic System & Lunar Plane				
Heat Sinks:				
Walls	19, 530 sf	65.00	1, 275, 000	
Lunar Plane (or floor)	1, 600 sf	94.00	150, 000	Electrical wiring, Regulators and Heating Elements for Lunar Plant - Included with Item J (a)
Helium Cryocondensers & Nitrogen Shields	1, 180 sf 1, 770 sf	76.00	225, 000	
Piping Systems:				
Nitrogen Heat Sink Wall & Lunar Plane	Lot	--	450, 000	Inside Chamber & Outside Piping to Connect with Supply & Return Headers

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
C. Cryogenic System & Lunar Plane (Cont'd)		$	$	
Piping Systems, cont'd				
Helium Panel Piping	Lot	--	260,000	Inside Chamber & Vacuum Jacketed Lines Outside Chamber to Connect with Main Header
Thermal Insulation (Thermal Shield)	--	--	--	Aluminum Thermal Shield Installed Between Heat Sinks and Chamber Wall included with heat sink panels
Instruments & Controls:				
Heat Sinks	Lot	--	210,000	
Cryo Condensers	Lot	--	30,000	
	SUB TOTAL		$ 2,600,000	
D. Instruments & Controls				
Solar Simulators	1 Lot	--	165,000	
Cryogenic System	1 Lot	--	147,000	
Vacuum Pumping	1 Lot	--	284,000	
Safety Shut Down	1 Lot	--	21,000	
Video	1 Lot	--	18,000	
Position -(Turntable)	1 Lot	--	43,000	
Instrument Wiring & Cable	525,000 lf	0.42	220,000	
Connections	25,000 ea	4.10	103,000	
Penetrations & Connections	3,500 ea	26.20	92,000	
Copper Tube & Small Pipe	10,900 lf	4.40	48,000	
Patch Panels	allow		23,000	
Cable Trays	2,100 lf	20.50	43,000	
	SUB TOTAL		$ 1,207,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
E. Data Handling (Less leased equipment)		$	$	
Penetrations:				
Shaft Cables	Lot	--	41,000	
Connector Plates				
Penetrations Cables				
Chamber Junction Box	Lot	--	35,000	
Control Room - Junction Box Cables	Lot	--	28,000	
Patching Panel	Lot	--	33,000	
Test Director & Bio Medical Console	Lot	--	47,000	
Analog Display Panel	Lot	--	20,000	
Computer Cables	Lot	--	15,000	
Misc. Material & Installation labor	Lot	--	98,000	
		SUBTOTAL	$ 317,000	

F. Bio Medical Facilities

Bio Medical capability is included in the Data Handling Estimate as follows:

a. Umbilical Electrical connections are costed under Penetration Cables	--	--	--	
b. Umbilical Switching is included in the Chamber Junction Box	--	--	--	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
F. Bio Medical Facilities (Cont'd)		$	$	
c. Bio Medical Monitoring & Displays are costed under the Test Director and Bio Medical Console to the extent envisioned in the Data Handling Requirements. Inasmuch as it is now assumed NASA will utilize a computer, the Bio Medical Console should be designed to be an integral part of the Test Director.		--	--	
Umbilical Connections:				
Double Man Lock	6 units	--	$ 18,000	
Single Man Lock	3 units	--	9,000	
Chamber Vessel	10 units	--	30,000	
O-ring seals & Flg. Bolts	Lot	--	3,000	
Rescue & Life Support Equipment	--	--	--	Not Included in this Facility
Bio Medical Room Equipment	--	--	--	Not Included in this Facility
Breathing Console	--	--	--	Not Included in this Facility
	SUB TOTAL		$ 60,000	These last three (3) items will be supplied by NASA

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
G. Special Handling System		$	$	
Turntable Mount	1 ea	--	178,000	45' Diameter
	SUB TOTAL		$ 178,000	
H. Mechanical Pumping Systems				
a. Rough Pumping:				
Foundations (Equipment)	25 cy	120.00	3,000	This System Common to Both Chambers A & B
Equipment: 5-stage Mechanical Blower System, incl. Motors Intercoolers, Blowers, Flexible Connections & Interconnecting Manifolding 2- 200 CFM Mech. Pumps 1- 100 CFM Mech. Pumps	Lot	--	185,000	
Piping, Valves & Hangers	1 Lot	--	145,000	
b. Vacuum Pumps:				
Equipment: 32" Diffusion Pumps 35" Diffusion Pumps 2000 CFM Booster 200 CFM Booster Interconnecting Manifolding	4 ea 10 ea 1 ea 1 ea 1 Lot	--	321,000	
Piping, Valves & Hangers	1 Lot	--	25,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
H. Mechanical Pumping Systems (Cont'd)				
c. Man Lock Pumping:		$	$	This Item applies to Chamber A Only
Equipment:				
5000 CFM Booster Pumps	2 ea			
1000 CFM Booster Pumps	2 ea	--	50,000	
200 CFM Mechanical Pumps	2 ea			
Piping, Valves & Hangers	Lot	--	35,000	
d. Compressed Air System:				
Foundations: (Equipment)	20 cy	150.00	3,000	Consists of small pump and equipment pads poured on floor slab
Equipment:				
Centrifugal Compressors	3 ea			
Reciprocating Compressors	4 ea	--		
Air Dryer	1 ea		60,000	
Associated Equipment	1 Lot			
Piping, Valves, Hangers & Specialties	--	--	130,000	
e. Cooling Water Systems:				
Foundations (Equipment & Cooling Towers)	25 cy	120.00	3,000	This System is Common for both Chambers A and B
Equipment:				
Circulating Water Pumps	2 ea			
Cooling Tower Pumps	1 ea			
Booster Pump	1 ea	--	25,000	
Chemical Injection Pumps	1 ea			
Cooling Tower	1 ea			
Piping, Valves & Specialties	1 Lot	--	115,000	
SUB TOTAL			$ 1,100,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
I. Chamber Repressurization (Normal & Emergency)		$	$	
a. Oxygen Supply:				
Foundations:	20 cy	100.00	2,000	
Structural Supports for Oxygen Bottles	25 T	480.00	12,000	
Oxygen Bottles	36 ea		56,000	12" Ø by 40' High Pressure
Pipe, Valves, Supports, Special Ties & Insulation	Lot		90,000	
b. Atmospheric Air:				
Air Inlet Filter with Structural Supports	2 ea		60,000	
Piping, Ductwork & Valves	Lot		70,000	
	SUB TOTAL		$ 290,000	
J. Electrical Power				
a. Solar, Albedo and Lunar Plane 480 V. Distribution Panelboards Comb. Motor Control #2 (Lunar Plane) Regulator (100%) & Rectifier Unit (Lunar Plane) Wire and Conduit Cable Trays	Lot	--	105,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
J. Electrical Power (Cont'd)		$	$	
b. Backing Pumps, Diffusion Pumps and ManLock Mechanical Pumps 480 V Motor Control Center Diffusion Pump Heaters Wire and Conduit Cable Trays	Lot	--	55,000	
c. Roughing Pumps, Air Compressors and Cooling Water System 480 V Motor Control Center Wire and Conduit Cable Trays	Lot	—	30,000	These Facilities are common to both Chambers A and B
	SUB TOTAL		$ 190,000	
K. Acceptance Tests	allow		$ 300,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
2. CHAMBER B - SPACE SIMULATOR		$	$	
A. Chamber B				
Foundation:				
Earthwork	2,500 cy	5.00	12,500	Includes 2000 cy of excavation and 500 cy selected compacted sand backfill, shoring and dewatering.
Concrete	500 cy	90.00	45,000	Includes form, reinforcing water proofing, imbedded metal items, concrete and pouring.
Piling	1,600 lf	10.00	16,000	Step tapered-pound in place.
Drain System	allow		2,500	Includes sump pump & piping.
Chamber Vessel, Complete including the following:			872,000	
a. Removeable Top Section	1 ea			
b. Struct. Platform Inside Chamber	1 ea			
c. Penetrations:				
Vacuum Pumps-48"dia.	12 ea			
Solar Simulators-18"dia.	1 ea			
Future Solar Simulators-18"dia,	16 ea			
Repressurization Ports-48"dia	4 ea			
Viewing Ports	Allowance			
Nitrogen Supply & Return Lines	Allowance			

DESCRIPTION	QUANTITY	UNIT COST $	TOTAL COST $	REMARKS
d. Support for Fixed Vehicle Mount	Allowance			
e. Personnel Locks:(C. S) Double Man Lock	1 ea			
f. Clean & Test				
Thermal Insulation		NONE REQUIRED		
Painting	allowance	--	2,000	
	SUB TOTAL		$ 950,000	
B. Solar & Albedo Simulation				
Simulation Modules:				
Top Sun	1 ea	--	60,000	Only one(1) lamp is included for this simulation module.
Electric Power:				Electrical for solar simulator has been included in Item J(a)
Solar Simulator	---		---	
Lunar Plane	---		---	
	SUB TOTAL		$ 60,000.	
C. Cryogenic System & Lunar Plane				
Heat Sinks:				
Walls	2810 SF	$68.00	190,000	
Lunar Plane (or floor)	700 SF	92.00	64,500	Electrical Wire, Regulators and Heating Elements, incl. with Item Ja.

	DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
	Helium Cryo Condensor		NONE	INCLUDED	
	Piping System:				
	Nitrogen	Lot	$ --	$ 137,000	
	Insulation (Thermal Shield)		--	--	Incl. w/wall panels. Alum Thermal Shield installed between Heat Sinks and Chamber Wall
C.	Cryogenic System & Lunar Plane				
	Instruments & Controls	Lot	--	43,500	
		SUB TOTAL		$ 435,000	
D.	Instruments & Controls				
	Solar Simulators	1 Lot		42,000	
	Cryogenic System	1 Lot		48,000	
	Vacuum Pumping	1 Lot		143,000	
	Safety Shutdown	1 Lot		13,000	
	Video	1 Lot		11,000	
	Wire	290,000 lf	0.42	122,000	
	Connectors	15,000 ea	4.25	63,000	
	Penetrations & Connections	3,000 ea	26.50	80,000	
	Copper Tube & Small Pipe	4,000 lf	5.00	20,000	
	Patch Panels	allowance		14,000	
	Cable Tray	1,500 lf	20.00	30,000	
		SUB TOTAL		$ 586,000	
E.	Data Handling (Less leased equipment)				
	Penetrations:				
	Shaft Cables Connector Plates Penetratinns Cables	Lot	--	22,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
Chamber Junction Box	Lot	--	$ 34,000	
Control Room-Junction Box Cables	Lot	--	28,000	
Patching Panel	Lot	--	33,000	
Test Direction and BioMedical Console	Lot	--	47,000	
Analog Display Panel	Lot	--	21,000	
Computer Cables	Lot	--	15,000	
Misc. Material & Installation Labor			70,000	
	SUB TOTAL		$ 270,000	

F. Bio-Medical Facilities

Bio-medical capability is included in the Data Handling Facilities as follows:

a.	Umbilical Electrical connections are costed under Penetration Cables	--	--
b.	Umbilical Switching is included in the Chamber Junction Box	--	--
c.	Bio-Medical Monitoring & Displays are costed under the Test Director and Bio-Medical Console to the extent envisioned in the Data Handling Requirements. Inasmuch as it is now assumed NASA will utilize a computer, the Biomedical Console should be designed to be an integral part of the Test Director.	--	--

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
Umbilical Connections:				
Double Man Locks	6 ea	$	$ 18,000	
Chamber Vessel	5 ea		15,000	
O-ring seals & Flg. Bolts	Lot		2,000	
Rescue and Life Support Equip.	--	--	--	Not included in this Facility
Bio-Medical Room Equipment	--	--	--	Not included in this Facility
Breathing Console	--	--	--	Not included in this Facility
	SUB TOTAL		$ 35,000	
G. Special Handling System				
Fixed Vehicle Support Mount	--	--	48,000	
	SUB TOTAL		$ 48,000	
H. Pumping Systems				Common with system for Chamber A - For Cost, See Item H - Chamber A
a. Rough Pumping	--	--	--	
b. Vacuum Pumps:				
Equipment:				
32" Diffusion Pumps	4 ea			
35" Diffusion Pumps	8 ea			
1000 CFM Booster Pumps	2 ea	--	277,000	
100 CFM Back Up	2 ea			
Interconnecting Manifolding	1 Lot			
Piping, Valves & Hangers	1 Lot		25,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
H. Pumping Systems (Cont'd)		$	$	
c. Man Lock Pumping:				
Equipment:				
5000 CFM Boosters	2 ea	--		
1000 CFM Boosters	2 ea	--	51,000	
200 CFM Mechanical Pumps	2 ea	--		
Piping, Valves & Hangers	Lot	--	30,000	
d. Compressed Air Systems	--	--	--	Common with system for Chamber A - For Cost See Item H - Chamber A
e. Cooling Water Systems	--	--	--	Common with systems for Chamber A - For Cost See Item H - Chamber A
	SUB TOTAL		$ 383,000	
I. Chamber Repressurization (Normal and Emergency)				
a. Oxygen Supply:				
Foundations	16 cy	125.00	2,000	
Structural Support for Oxygen Bottles	16 T	500.00	8,000	
Oxygen Bottles	24 ea	--	38,000	
Piping, Valves, Supports, Specialties & Insulation	Lot	--	60,000	
b. Atmospheric Air				
Air Inlet Filter with Structural Support	1 ea	--	20,000	
Piping, Ductwork & Valves	1 Lot	--	25,000	
	SUB TOTAL		$ 153,000	

DESCRIPTION	QUANTITY	UNIT COST	TOTAL COST	REMARKS
J. Electrical Power		$	$	
a. Solar, Albedo & Lunar Plane 480 V Distribution Panel board Motor Control Center (Lunar Plane) Regulator (100%) & Rectifier Unit Wire & Conduit, Cable Trays, etc.		---	23,000	
b. Backing Pumps, Diffusion Pumps and ManLock Mechanical Pumps 480 V Motor Control Center Diffusion Pump Heaters Wire, Conduit & Misc.		---	37,000	
c. Roughing Pumps, Air Compressors and Cooling Water System		---	---	Common with Facilities for Chamber A - Cost incl with Chamber A, See Item J c.
	SUB TOTAL		$ 60,000	
K. Acceptance Tests			$ 100,000	

DESCRIPTION	TOTAL COST
	$
V. ABNORMAL DESIGN COSTS	
1. Foundation Studies	25,000
a. Core Drillings & Soil Consultants	
b. Pile T[illegible] if required	
c. Special Foundation Consultant for Large Compressor Foundations	
d. Foundation Consideration & Studies for Future Module Shaker Tests	
2. Extraordinary Design	600,000
a. Study and Consideration for Future Upgrading of Facility to Accommodate Shaker Tests	
b. Reliability Studies and Tests	
c. Quality Assurance	
d. Development of Mount Drive for Vacuum Service	
e. Definition and Scoping of R & D Problems	
f. Man Rating	
g. Design Adjustments and Changes as a Result of R & D	
h. Study Module or Vehicle Test Requirements	
i. Intergration with Evolving Design of Apollo Vehicle	
j. Adjusting Design to Accommodate Evolving Test Programs	
k. Facility Scale Model Requirements	
l. Coordination with MSC, B&R, C.E., N.A.A & Others	
m. Coordinate Design Sub Contracts with Facility	
n. First Time Design for Equipment and Services	
o. Vehicle Mount and Lunar Plane	
p. Test Data Handling Equipment	
q. Solar Simulator	
r. Specialized Cryogenics	

DESCRIPTION	TOTAL COST
	$
Extraordinary Design (Cont'd)	
s. Emergency Repressurization	
t. Specifications for Government Leased Items	
u. Coordination and Integration of Government Leased Facilities	
v. Special Instrumentation	
w. Qualification of Supervision	
3. Extraordinary Consulting Service	50,000
a. Soil Bearing Consultants	
b. Test Article - Shaker Consultant	
c. Soil Compaction Control	
d. Construction Material Testing	
e. Upgrading Facility for Shaker Tests	
f. Man Rating	
g. Study of Vehicle Test Requirements	
h. Advance Vacuum Technology	
i. Advance Vacuum Vessel Design Technology	
4. Construction Contract Changes	90,000
a. Partial Bid Package	
b. Project Design Schedule	
c. Coordination with MSC, B&R, CE and Others	
d. Overlapping of Design and Construction	

DESCRIPTION	TOTAL COST
5. Requirements for and Review of Shop Drawings	$ 60,000
a. Service to Government Contracting Agency	
1. Review Detail Shop Fabrication Drawings for Vessels and Structural Steel	
2. Review Vendors Equipment Drawings	
3. Review Contractors Final Design	
b. Complexity of the Facility and the Number of Construction Changes	
6. Monitoring Acceptance Tests	50,000
a. Component Parts and Complete Facility	
b. Special Personnel Qualifications	
c. Effect of Construction Sequencing	
d. Special Test Equipment	
e. Coordination of Test Procedures	
f. Test Data Evaluation	
g. Establish Test Standards	
h. Helium System	
i. Vacuum Seals	
j. Solar Simulators	
7. Maintenance and Operating Manuals	275,000
a. Special Qualified Personnel	
b. Dual Chamber Control and Support Facilities	
c. Project Schedule	
d. Vehicle Test Data System	

DESCRIPTION	TOTAL COST
8. <u>Trouble Shooting</u>	$ 30,000
a. First Time Equipment Design b. Specialized Systems c. First Time Systems Design d. Critical Nature of High Performance Levels e. Number of Contributing Agencies & Contractors	
9. <u>Cost of Training Government Personnel</u>	40,000
a. Advanced Technology b. Complexity of Facility c. Project Schedule d. Teachers, Models, Mock Ups, Training Aids, ,etc.	
10. <u>Safety Considerations</u>	30,000
a. Man Rating b. Explosive Hazards c. Toxic Hazards d. Cryogenic Hazards	

DESCRIPTION	CAPITAL COST
	$
REFRIGERATION	
Nitrogen Reliquefier 280 KW	2,500,000
Nitrogen Storage:	200,000
1 - 100,000 gal. Tank	
1 - 27,000 gal. Tank	
Circulation Pumps and Supply and Return Lines to Chambers	250,000
Helium Refrigeration Unit 7.5 KW	1,240,000
Helium Storage	40,000
Helium Supply and Return Piping	90,000
Refrigeration Building	150,000
Equipment Foundations	80,000
Refrigeration-Cooling Water, including Cooling Tower	80,000
Electrical Power - Transformers and Switchgear included	170,000
	$ 4,800,000
DATA HANDLING EQUIPMENT (Computer)	
1 - Process Computer System	$ 600,000

CHAMBER D FACILITY

DESCRIPTION	PRELIMINARY ESTIMATE
Chamber D	
Solar Simulator	400,000
5^{o}K Liquid Helium Refrigeration Plant & Cryogenic System (Liquid & Gaseous Nitrogen To Be Supplied From Nitrogen Refrigerator For Chamber A & B)	2,200,000
Chamber Shell & Vacuum Pumping	225,000
Building Extension	100,000
Instruments, Controlls & Data Handling	225,000
Site Development & Electrical Distribution	50,000
Total	$ 3,200,000
Alternate: Chamber D — Substitute 20^{o}K Helium Refrigeration for the 5^{o}K System. Would result in net saving of $1,100,000	
Total	$ 2,100,000

SECTION III
CONSTRUCTION SCHEDULE

1.0 Recommended Schedule - The "Partial Bid Backage" form of construction project is recommended as it provides the most expeditious and reasonable schedule available with normal Grovenment agency contractual procedures. This approach is estimated to provide the facility with both chambers ready for test operation 21 months after start of design, with minor premium costs. The schedule is illustrated by Fig. III-1, based on a June 1, 1962 Start of Work.

2.0 Type of Project - This method provides the Government with a series of bid packages of plans and/or specifications which are awarded on a competitive bid basis for the furnishing of long lead items. A final bid package for complete construction responsibility is let by the Government for all other items including overall facility construction integration, including the long lead items, but excepting installation of leased facilities.

3.0 Breakdown of Classification - Breakdown of the various classifications is as follows:

a. Criteria-Performance specifications, with vendor responsibility for finished design and construction or installation: Vessels

A and B, Refrigeration System, Data Handling System.

b. Criteria-Performance specifications for engineering and manufacture with prime construction contractor responsibility for installation: Vacuum System; Radiation Simulation System, Turntable for A and Fixed Mount for B.

c. "Partial Package" items consisting of plans and specifications for services, materials and construction: Site work, excavation and foundations; structural steel and buildings.

d. 'Engineering Specifications for long lead items for procurement only: Plant Air System; electrical, controls and instrumentation; mechanical equipment, 50 ton crane, etc.

e. q Prime construction contract single package for all other items and responsibility for integration of all items into complete facility ready for turn-over.

4.0 Advantage of Partial Bid Package - This Partial Bid Package approach to the project has the advantage over the "Prime Contract-Complete Bid Package" of providing the earliest practicable effort on numerous critical items of procurement and construction. It has the disadvantage, in relation to a CPFF Turnkey contract, of delaying the prime construction contract award until all engineering is completed and of delaying all other items for substantial bid and award periods as compared to the expeditious in-house approach of CPFF Turnkey

procedure, where the Architect-Engineer is the prime construction contractor.

The schedule, based on the "Turnkey" method, appears to be, on a preliminary estimate basis, of some two-to three months shorter duration than that attainable by the "Partial Bid" method.

5.0 Qualifications - Several qualifications on this approach are:

a. Vessels A and B fabrication and erection are based on two shift operation (straight-time) and a premium of $102,000.

b. All other items are on a straight-time basis.

c. There are indications that vendors will not bid on the development of the solar simulation system on a lump sum basis, although they probably would agree to manufacture on a fixed-price basis after the developmental phase.

6.0 Critical Items - Critical items are:

a. The burden on engineering to produce complete drawings and/or specifications for the early items.

b. The long lead times of several items.

c. The scheduling of several activities for simultaneous performance, in limited work space areas.

d. The necessity for close coordination of all procurement and installation and testing.

e. The necessity for maintaining the scheduled sequences for "fixed-date" items, such as vessel completion, data handling system completion, etc.

f. The weather - The effects of which must be absorbed in the schedule.

7.0 <u>Research and Development</u> - It is not considered likely that R & D recommended for the project would significantly affect the completion date of the schedule shown. The major item of prototype evaluation for the radiation simulation module is allowed for in the lead time, and scheduling of the other systems possibly involved, such as emergency repressurization, instrumentation, and man rating features do not appear critical or governing on early facility operation.

8.0 These schedules are subject to revision if future guidance from Government agencies is not consistent with the assumptions made in the study. Further detail studies on bid package requirements are necessary to determine specific key dates in the schedule. The line items in the schedule shown are not necessarily the bid package breakdown which will be found best suited to meet project needs. The dates of award shown are approximate only and may indicate the initial award of a series of subpackages to accomodate the sequence of design information becoming availabl

PARTIAL BID PACKAGE

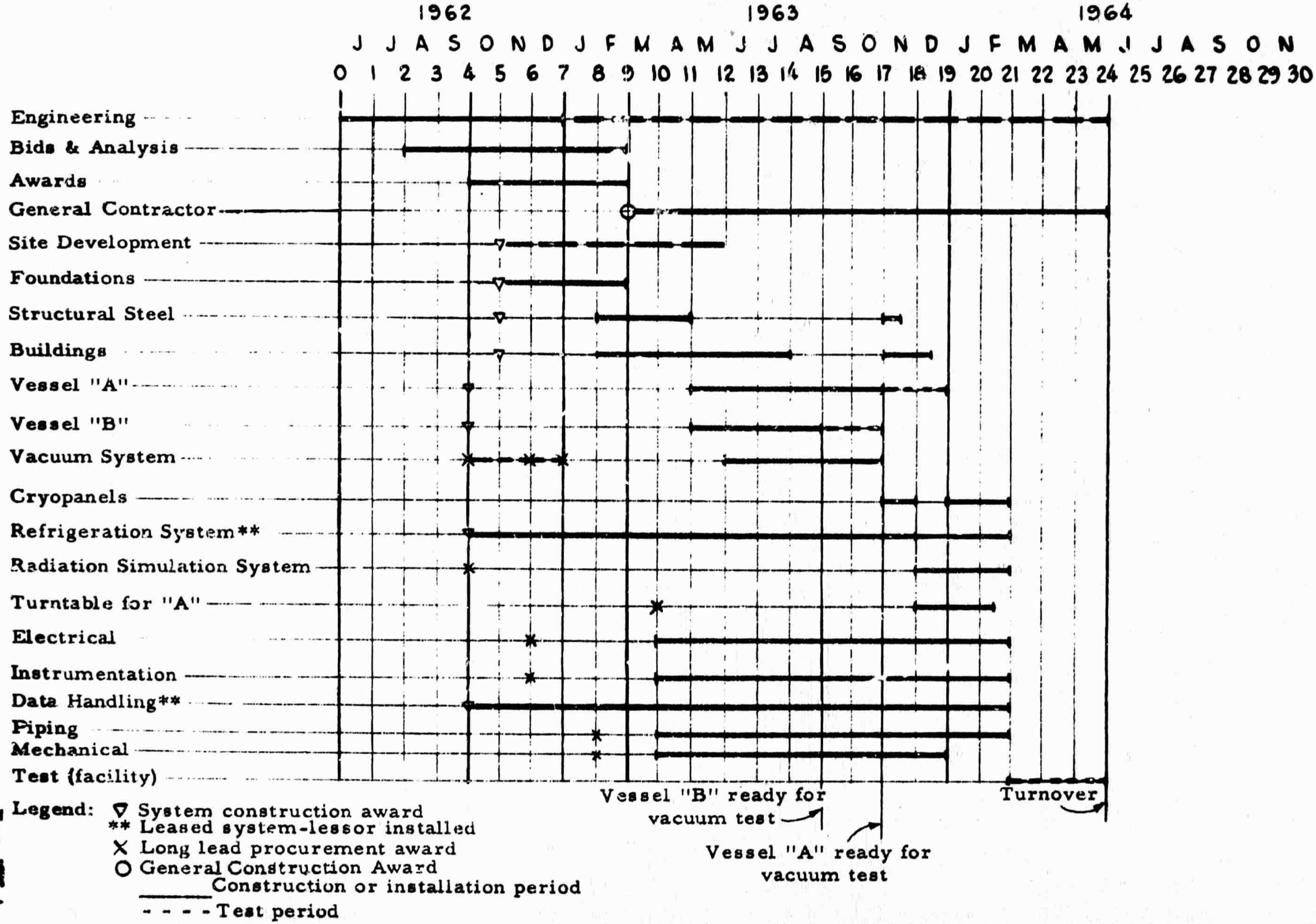

FIG. III-1

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SECTION IV
RESEARCH AND DEVELOPMENT

1.0 General - During design studies of test facilities on the frontier of current technology, areas are frequently encountered in which a lack of information is evident. The purpose of this Section is to summarize such areas that are considered to be beyond the scope of normal engineering. It is believed that additional effort should be expended to clarify these points. Further effort is required to develop or plan these research and development programs and to estimate the amount of effort required to obtain satisfactory basis for proceeding with the design. In no case, however, is it believed that construction of the facility involving Chambers A and B need be delayed to await results of research and development.

1.1 Diffusion Pump Oils - Man rating of the chambers requires emergency repressurization with an oxygen enriched gas, hence, a possibility of an explosive reaction with diffusion pump oils which must be prevented. While this study yielded some information on the effects upon the spontaneous ignition temperature of oils with changes of oxygen partial pressure, considerable uncertainty still exists. A program is required to determine the oxygen compatibility of candidate oils and confirm that the selected oil can be used safely.

The back streaming of diffusion pump oils during operation at the intermediate pressure levels of 10^{-4} to 10^{-5} torr should also be investigated further. It is in this range that the jets begin to form and the back-streaming rates are not fully known. The need for a program to determine these rates is related to the tolerance of diffusion pump oils inside the chamber.

1.2 Solar Simulator - The solar simulator modules recommended in this study are on the border line of current technology. While the conceptual design is sound, no such modules have been constructed. It has been found to be unwise to attempt to design and procure such units in the normal manner without first undertaking the construction of a protype module with an adequate schedule for testing and modification before fabrication of the final units. This program might have a significant effect upon the ultimate completion of the facility unless the development program is initiated early in the project.

1.3 Emergency Repressurization - One of the areas requiring experimental verification of the theoretical results will be the equilibrium temperature of gases inside the chamber immediately following emergency repressurization. The final temperature of gas inside the chamber could cover a wide range and create hazards to personnel as a result of action taken to reduce other hazards.

The highly complex thermodynamic processes involved in repressurization practically defy adequate analysis and the final scheme for repressurization should be based on experimental results. The intensity of shock waves impinging upon personnel and equipment and peak noise levels also require further investigation. Fortunately, solutions to these problems can probably be obtained with relatively small effort in an existing facility by a direct experimental program.

1.4 Remote Indicating Ionization Gauge - While thermocouple and alphatron pressure gauges present no difficulty in remote indication, satisfactory read-out from ionization gauges is limited to about 100 ft. For a facility of the size being contemplated, gauges will be considerably farther from the control room. A program should be initiated to determine the best way in which signals from the ionization gauges can be transmitted.

1.5 Flexible Cables to Vehicle - Additional work will be required to establish the means by which hard wire communication between the vehicle and its control system and the data handling system can be implemented. In areas outside the solar beam, such cables would be subject to very low temperature and conventional materials are likely to become brittle, cracked, and stiff. The feasibility of using internal heaters to maintain flexibility must be established.

1.6 Man Rating - Man rating of space environment test chambers still involves an extrapolation of demonstrated technology in some areas. The uncertainty of such parameters as the required oxygen content of repressurization gas has an important influence on the design of the repressurization system. While much of the uncertainty may remain in this area due to the variableness of individuals and the desire to maintain a reasonable margin of safety, additional effort in this area may help establish the minimum requirements of oxygen. This result would influence final selection of a repressurization system using stored gas versus atmospheric air.

1.7 Space Suits - While space suits currently under development will undoubtedly be adequate for the space mission, they will not necessarily be compatible with requirements for use in test chambers. Therefore, the development program for flight suits must take account of the chamber requirements or special suits must be developed. Compatibility of umbilical connections will be required. Suits used in the chambers should also have a minimum attainable leak rate and be invulnerable in contact exposure to surfaces from about -320°F (heat sink) to about 260°F (lunar plane).

1.8 Space Chamber for Systems Tests Under Extreme Vacuum - This chamber is not included in the selected facility for initial con-

struction. The concept of this chamber is beyond current technology which has been demonstrated. Straight forward design and procurement in the normal manner for off-the-shelf facilities is not recommended in this case. The chamber will, in its entirety, require a research and development effort. Specific areas of uncertainty are the means of providing visual observation of the test article, rotary seals for actuating mechanisms on the test article, leak detection methods, and materials. Since this is a primary research and development program, considerable discussion is devoted to it in Volume II, Section XV.

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VOLUME II - STUDIES AND RECOMMENDATIONS

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Figures

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SECTION I
INTRODUCTION

1.0 Background - Bechtel Corporation, as prime contractor to the Manned Spacecraft Center of the National Aeronautics and Space Administration, undertook, under Contract No. NAS 9-419, design studies of the space environment simulation chambers required at the Center. Associated with Bechtel Corporation were several companies with technical responsibilities as follows:

Air Products and Chemicals, Inc.	Cryogenics
Bausch & Lomb, Inc.	Radiation Simulation
Chicago Bridge & Iron Co.	Chamber Vessels
FMC Corporation	Special Mechanisms
General Electric Co. - MSVD	Data Handling & Man Rating
National Research Corp.	Vacuum

This study was a 60-day effort to determine the optimum space chamber facility to meet the requirements of the Manned Spacecraft Center within a limited construction budget.

2.0 Other Project Reports - This volume is a documentation of the studies that were undertaken and the recommendations that were made to MSC. It is the second volume of the final report. Volume I contains a brief description of the recommended facility, a construction cost estimate, a construction schedule, and a summary of research and development recommended to carry out the project.

Volume III presents Design Criteria for the recommended facility and a more detailed description of the conceptual design from which the Design Criteria were derived.

3.0 Technical Notes - Throughout the study, various investigations were documented by internal memoranda designated as technical notes. These technical notes are frequently referred to in the present volume by coded symbols that indicate the originating company and the serial number of the report. For example, BTN-10 refers to Bechtel Technical Note No. 10. These reports, being too voluminous to include in this final report of the project, are summarized in this document and specific references are given to more detailed discussions of various topics.

4.0 Project History - On April 1, the project team was assembled in temporary offices in Houston, Texas. Preliminary meetings were held with the Working Committee for Space Environment Simulation Chambers and other representatives of the Manned Spacecraft Center to establish the basic requirements of the facility being studied. Technical Guidelines, appended to the contract, were reviewed. MSC provided extensive supplementary material summarizing the background of requirements for the test facilities. One of the basic guidelines was to determine the optimum testing capability that could be achieved within a limited construction budget. Thereafter, auxiliary meetings were held to clarify certain requirements and to mutually establish the basis for proceeding with the conceptual designs. The prime contractor and associated subcontractors formally reviewed the Guidelines and submitted comments and recommended changes to the Committee intended to make the Guidelines sufficiently flexible so that the initial phases of work would be guided in the most productive channels.

These comments were incorporated in the Guidelines. During the subsequent two weeks, comparative studies were undertaken to determine the best solutions to the many problems associated with defining conceptual designs of four test chambers. In many instances, several promising ways of accomplishing the objectives were investigaed. Economic trade-offs were evaluated and specific design approaches were recommended. At this stage of the study, the individual chambers were considered to be separate operating facilities to simplify the task and to explore the economic implications of constructing the four facilities as independent units. Construction cost estimates were then prepared for each of the four test chambers with their supporting facilities.

On April 13, a formal presentation was made to MSC covering the studies of the first phase. This presentation utilized about 50 charts summarizing then-current results of investigations. Different types of vessels for the chambers were presented along with evaluations based on the effect upon building size, the adaptability to expansion, and relative costs for different materials. Evaluation of various methods of vehicle handling such as side loading, top loading, and combinations thereof were also presented. Preliminary designs of vehicle handling equipment including dollies, turntables, and mounts, flow diagrams of pumping systems, schematic diagrams of repressurization systems, thermal loads in the chambers, alternate designs of heat sink panels, cryo-pumps, and their method of mounting, in conjunction with control zone arrangements and preferred refrigeration systems, were all presented. Studies also included a comparison between internal quartz lamps for thermal flux generation and external, optical systems.

Evaluation of various concepts of control and instrumentation were presented. Analyses of basic concepts of data handling systems were shown, based upon the number of channels required for vehicle data acquisition for ecological systems, and for facility performance records. The requirements for man-rating of the appropriate chambers were reviewed. Finally, a cost estimate of the four chambers was presented, and a breakdown of the estimate was presented to the Chairman of the Working Committee. Copies of the presentation charts were also submitted to the Chairman along with summaries of the individual discussions. The principal conclusions of the first progress meeting was that the cost of the four chambers which most closely met the operational requirements, substantially exceeded the budget, and that the variety of chambers considered and their performance levels required revision.

Several meetings followed in which the presentation material was reviewed in detail and possible alternatives were investigated such as the possibility of leasing the Refrigeration plant to remove it from the construction funding. As a result of these meetings, the Guidelines for the study were revised. The revised Guidelines deleted one of the chambers from further consideration and reduced requirements in the others such as the ultimate vehicle size and weight, the number of astronauts in the chamber at a given time, the operating pressures, the upgrading potential of solar flux intensity, the test duration, and in some instances, the operational parameters for the lunar plane.

The following two weeks activity was an intensified study of a combined complex consisting of the two larger chambers and the small extra-high vacuum chamber. It was recognized by MSC that the extra-high vacuum chamber would be found to be beyond the budget of the initial construction program for the complex. Economic analyses were undertaken to establish the relative costs of purchasing a Refrigeration plant in comparison to leasing the plant . Detailed investigations of the optimum combination of diffusion and cryogenic pumping was also undertaken. Thermal loads on the refrigeration plant were studied for various stages of the lunar mission to establish more precisely the design load for the plant and the requirements for liquid nitrogen storage. Further details were developed for the control and instrumentation concept and alternate vessel designs of smaller size were developed. A construction cost estimate of the combined test facility including the two larger chambers and the small one was presented along with several variations on the design concept and the corresponding incremental costs. At the second progress meeting on April 24, this material was discussed and copies of 18 charts and a summary were submitted. The conclusion of this meeting on April 26 was that a Facility consisting of the two

larger chambers meeting the Guidelines with some further revisions could be constructed within the budget.

Prior to closure of the temporary office in Houston, the principle project effort was graduallyshifted to a permanent office in San Francisco. The next several weeks were devoted to developing the conceptual design of the selected facility incorporating the Space and Lunar Surface Environment Simulation Facility (Chamber A) and the Space Chamber for Life Sciences and Astronaut Training (Chamber B). Further work on a lesser priority basis was carried out on the Space Chamber for Systems Tests Under Extreme Vacuum (Chamber D) although it could not be planned as an integral chamber of the facility due to budget limitations. The status of this effort was presented to representatives of MSC at the third progress meeting on May 15 at which a detailed review was made of the conceptual design of the facility. General approval by MSC was noted but certain areas requiring further definition were the subject of additional conferences to confirm the basis for the terminal effort of the study, including the drafting of the Design Criteria for the selected facility and for Chamber D.

The following sections describe in more detail the various technical areas investigated during this work, and include the backup information upon which the design criteria are based. The Design Criteria are presented in Part A of Volume III. Descriptions of the facility and equipment are presented in Part B of Volume III.

SECTION II
INTERNAL CLEAR SPACE REQUIREMENTS

1.0 Chamber A-Initial Studies - During the initial phase of the study, layout work on Chamber A was based on the Guidelines supplied by MSC. Chamber A space requirements were based on the following considerations.

1.1 Vehicle Size - The Guidelines provided for an ultimate vehicle 25 ft in diameter by 105 ft long, weighing approximately 100, 000 lbs. Possible appendages requiring clearances of 60 ft in diameter were also to be considered. For study purposes, this vehicle was assumed to be made up of modules with maximum dimensions of 25 ft diameter by 35 ft long and 10 ft diameter by 60 ft long. These modules were also used in preliminary vehicle loading and handling studies.

1.2 Solar Simulator - Preliminary study indicated a distance of approximately 20 ft was desired between lenses and vehicle surface, in order to secure reasonable uniformity and intensity. Both the top solar position and the side position require this spacing. This requirement governs the minimum vessel diameter and allows ample space for internal catwalks and direct access to the surface of the ultimate vehicle.

1.3 Cryogenic Panels - A space of 5 ft inside the vessel wall was allowed for heat sinks and cryopumping arrays, providing a 3 1/2 ft annular space for access behind the panels and allowing a nominal 18 inches for panel assemblies.

1.4 Turntable (Lunar Plane) - Study based on the preceding criteria showed that a minimum desirable turntable was 65 ft diameter to provide for the landing gear spread requirements.

1.5 Internal Vehicle Handling - Several alternate schemes were studied and are discussed in a later section. All schemes indicated that the space required by other considerations such as solar beam "focal length" would be sufficient for installation and servicing of the vehicle by individual modules. Loading an externally assembled full sized vehicle appeared to be almost impossible within economic limits.

1.6 Basic Chamber Dimensions - The initial phase studies produced a basic chamber with the following dimensions:

a. 75 ft shell diameter
b. 105 ft straight wall cylinder
c. 37 ft 6 inches radius hemispherical top head
d. D/3 semi-elliptical bottom head
e. 45 ft clear diameter door

This shape is shown on Fig. II-1. Other shapes studied were all based on the same minimum internal clearances, and are discussed in Section III.

2.0 Chamber A - Second Phase Studies - During the second phase of study, revised guidelines were received which included new vehicle sizes. These were incorporated into the chamber layouts, resulting in a new set of clearance dimensions. The variations are discussed below.

2.1 Revised Vehicle Size - The revised guidelines require the consideration of three alternate vehicles for Chamber A.

"a" 35 ft diameter by 75 ft long
"b" 35 ft diameter by 75 ft long, with landing gear requiring local clearances of 60 ft diameter
"c" 25 ft diameter by 75 ft long, with landing gear requiring local clearances of 40 ft diameter

All three vehicles weigh approximately 100,000 lbs. For handling (both internal and external) these vehicles were assumed to be made in modules not to exceed 35 ft diameter by 25 ft height for vehicles "a" and "b" and 25 ft diameter by 25 ft height for vehicle "c". The 10 ft diameter by 60 ft long configuration used in previous Chamber A handling studies was retained as an additional clearance requirement.

2.2 Revised Clearance Requirements - The new vehicle sizes all reduced the height requirement for Chamber A by 30 ft. In addition, vertical clearance of the top solar simulator was found to be excessive. This finding resulted in essentially two different chamber layouts; the first for vehicles "a" and "b", and a slightly smaller one for vehicle "c". Other clearance requirements were found to be essentially the same as previous layouts and these were retained. Fig. II-2 shows an evaluation drawing illustrating the alternate chambers for each vehicle along with relative costs. Briefly, vehicles "a" and "b"

each required a chamber 75 ft diameter and 67 ft straight side with the same hemispherical top and semi-elliptical bottom, developed in the initial phase. For vehicle "c", a 65 ft diameter cylinder was found to be practical and economically superior. Also the door diameter for vehicle "c" was reduced to 39 ft clear opening.

2.3 Selected Chamber - Chamber A-12 (65 ft diameter) was selected for the basis of the design criteria. Further minor variations of shape have been studied but have not proved any economic or physical advantage.

3.0 Chamber B - Initial Phase - Layout studies for Chamber B were based on the following requirements.

3.1 Vehicle Size - Initial guidelines gave a vehicle size of 13 ft diameter by 25 ft long, weighing 40,000 lbs with an estimated clearance requirement of 25 ft diameter by 35 ft long.

3.2 Solar Simulator - Studies indicated that for a 13 ft diameter vehicle, 10 ft to 11 ft between lens assembly and vehicle surface should be sufficient for solar flux requirements. Both top and side locations were to be provided.

3.3 Cryogenic Panels - For Chamber B, the same 5 ft space allowance as determined for Chamber A was used.

3.4 Turntable (Lunar Plane) - The turntable (or lunar plane) was basically determined in the same manner as that for Chamber A, and was shown as 25 ft diameter.

3.5 Internal Vehicle Handling - Due to the relative ease of top loading the chamber, internal handling problems for Chamber B are greatly simplified. It was found that no additional space beyond that already required by other considerations was necessary.

3.6 Basic Chamber Dimensions - The initial phase studies for Chamber B resulted in the following dimensions.

a. 35 ft shell diameter
b. 30 ft straight side
c. $^{D}/3$ semi-elliptical heads, top and bottom

This shape is shown on Fig. II-3. Additional detailed development was carried out in further studies.

4.0 Chamber B-Second Phase Studies - Revised guidelines which included new vehicle sizes were received and resulted in two alternate chamber sizes. The variations were as follows.

4.1 Revised Vehicle Sizes - The revised guidelines require the consideration of two different vehicles.

a. 13 ft diameter by 24 ft long, weighing 40,000 lbs
b. 13 ft diameter by 14 ft long, weighing 20,000 lbs

4.2 Revised Clearance Requirements - The new vehicle size of 14 ft long (vehicle "b") allowed a reduction in height of 10 ft for Chamber B. Two alternate chambers were developed; one for each vehicle size as shown on Fig. II-4 where it is noted that the basic difference is one of straight cylinder length only. Shape B-10, with 30 ft straight sides, was used for establishing crane lift requirements. Other space requirements developed in the initial phase of studies were found to be the same and were retained.

4.3 Selected Chamber - Chamber B-11, 35 ft diameter by 20 ft straight side, was selected for the basis of design criteria. It is easily adaptable by shell extension to providing the required additional space necessary to accommodate the longer vehicle "a".

5.0 Chamber C - Initial Phase - Layout studies for Chamber C during the initial phase were based on the following considerations.

5.1 Vehicle Size - The initial guidelines required two degrees of freedom (relative to solar simulator) of a vehicle 23 ft diameter by 18 ft long, weighting up to 60,000 lbs.

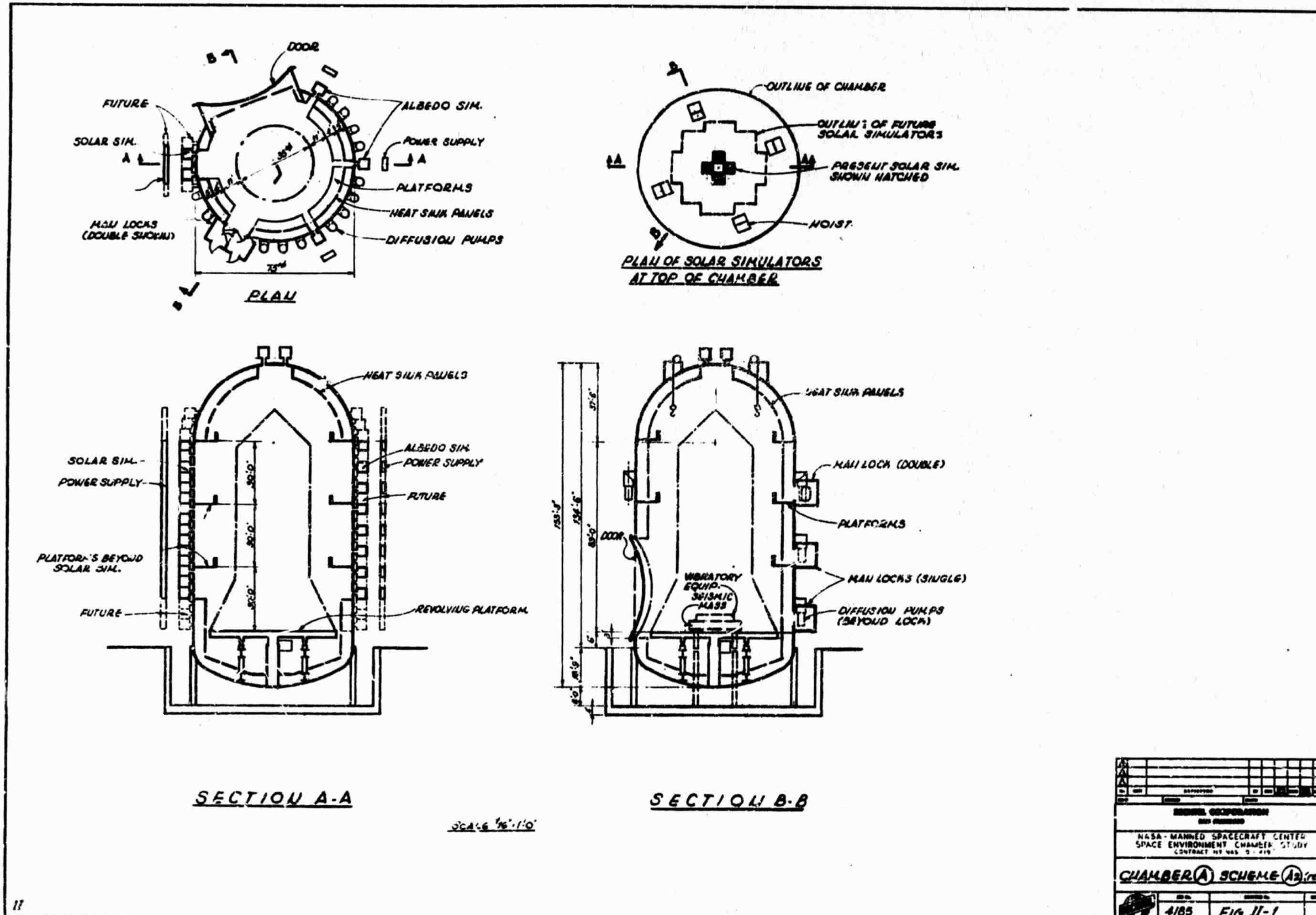
5.2 Mount Considerations - A gimbal mount was studied, in which the vehicle is carried within a rectangular frame. The corner clearances required for this first mount results in a preliminary chamber diameter of 54 ft. Further studies indicated the possibility of reducing the shell diameter to 40 ft. These variations are shown on Figs. II-5 and II-6.

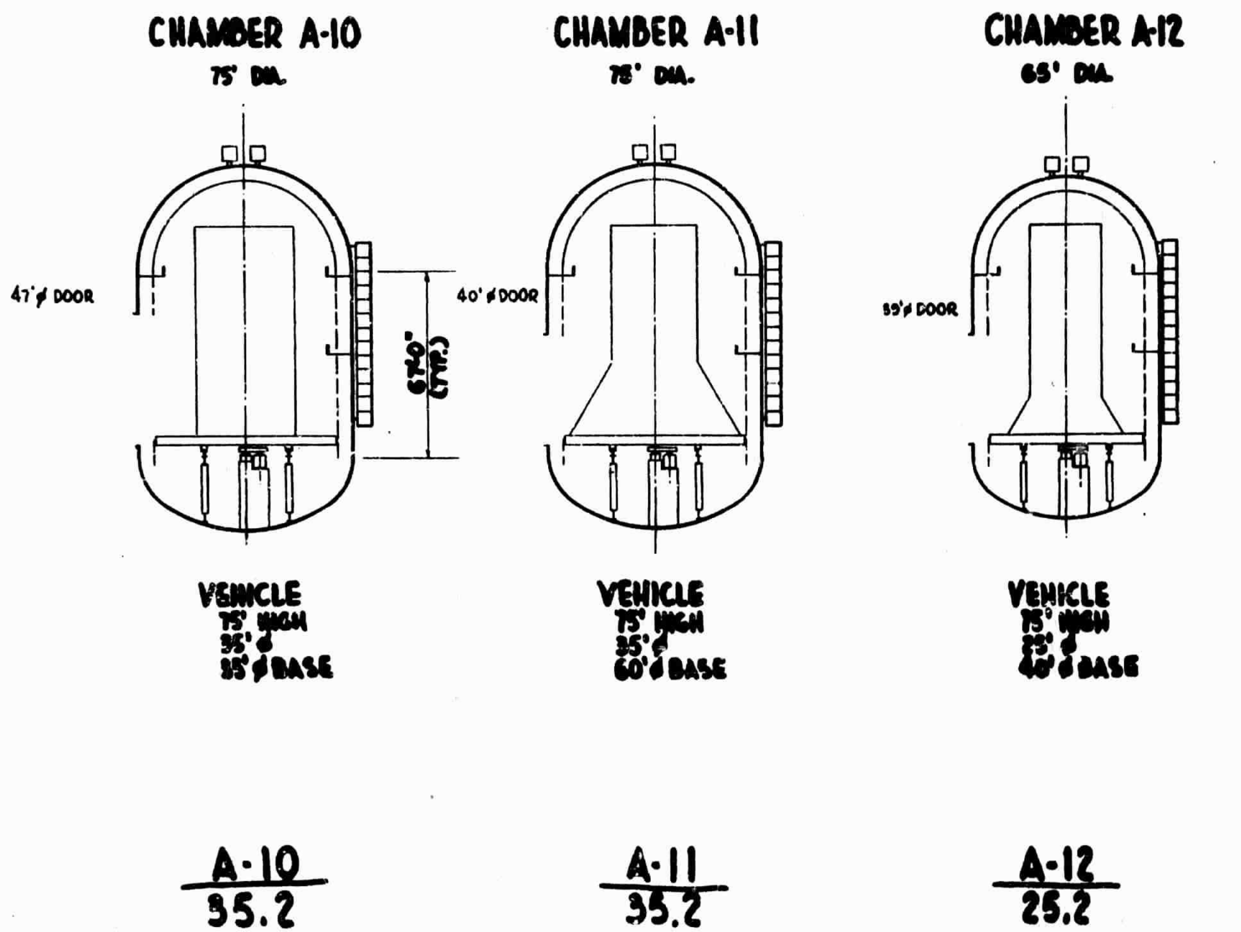
5.3 Solar Simulator - The solar simulator was located in the removable chamber top for initial studies. The space requirements were similar to Chamber A for lens to vehicle distance.

5.4 Cryogenic Panels - A 5 ft space allowance for heat sink and cryo pumping arrays was used for this study, based on the requirements derived in Chamber A development.

5.5 Internal Handling - Similar to Chamber B studies, it was found that other clearance requirements had provided the necessary space for internal vehicle handling. Top loading of the chamber was indicated as the most promising concept of vehicle installation within the gimbal.

5.6 Study Conclusion - Further development of the vehicle mount is necessary before final shell diameter can be firmly established although a 40 ft diameter seems to be possible. At the conclusion of the initial phase studies, it was directed that work on Chamber C be discontinued, and no further work was performed on these layout studies.


DOOR
FUTURE
ALBEDO SIM.
SOLAR SIM.
POWER SUPPLY
PLATFORMS
HEAT SINK PANELS
MAN LOCKS
(DOUBLE SHOWN)
DIFFUSION PUMPS
PLAN
OUTLINE OF CHAMBER
OUTLINE OF FUTURE
SOLAR SIMULATORS
PRESENT SOLAR SIM.
SHOWN HATCHED
HOIST
PLAN OF SOLAR SIMULATORS
AT TOP OF CHAMBER
HEAT SINK PANELS
SOLAR SIM.-
POWER SUPPLY-
ALBEDO SIM.
POWER SUPPLY
FUTURE
PLATFORMS BEYOND
SOLAR SIM.
REVOLVING PLATFORM
MAN LOCK (DOUBLE)
PLATFORMS
DOOR
VIBRATORY
EQUIP.
SEISMIC
MASS
MAN LOCKS (SINGLE)
DIFFUSION PUMPS
(BEYOND LOCK)
SECTION A-A
SECTION B-B
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CHAMBER (A) SCHEME (A2)
4185
FIG II-1
11

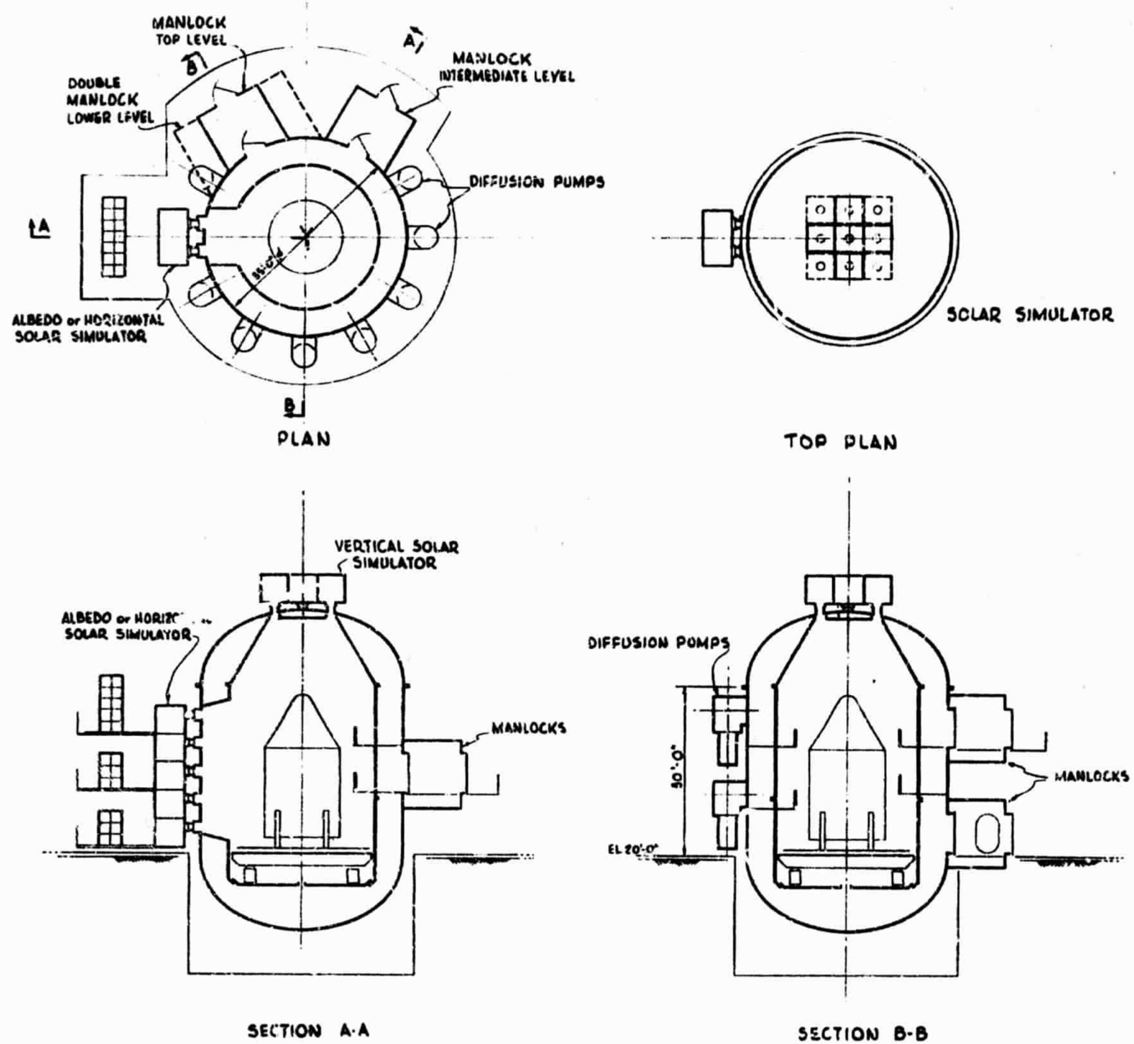


NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

CHAMBER A-10, A-11 & A-12

4185

FIG. 11-2



SCALE 1/8" = 1'-0"

CALC. VAC. LEVEL 4 x 10^-5

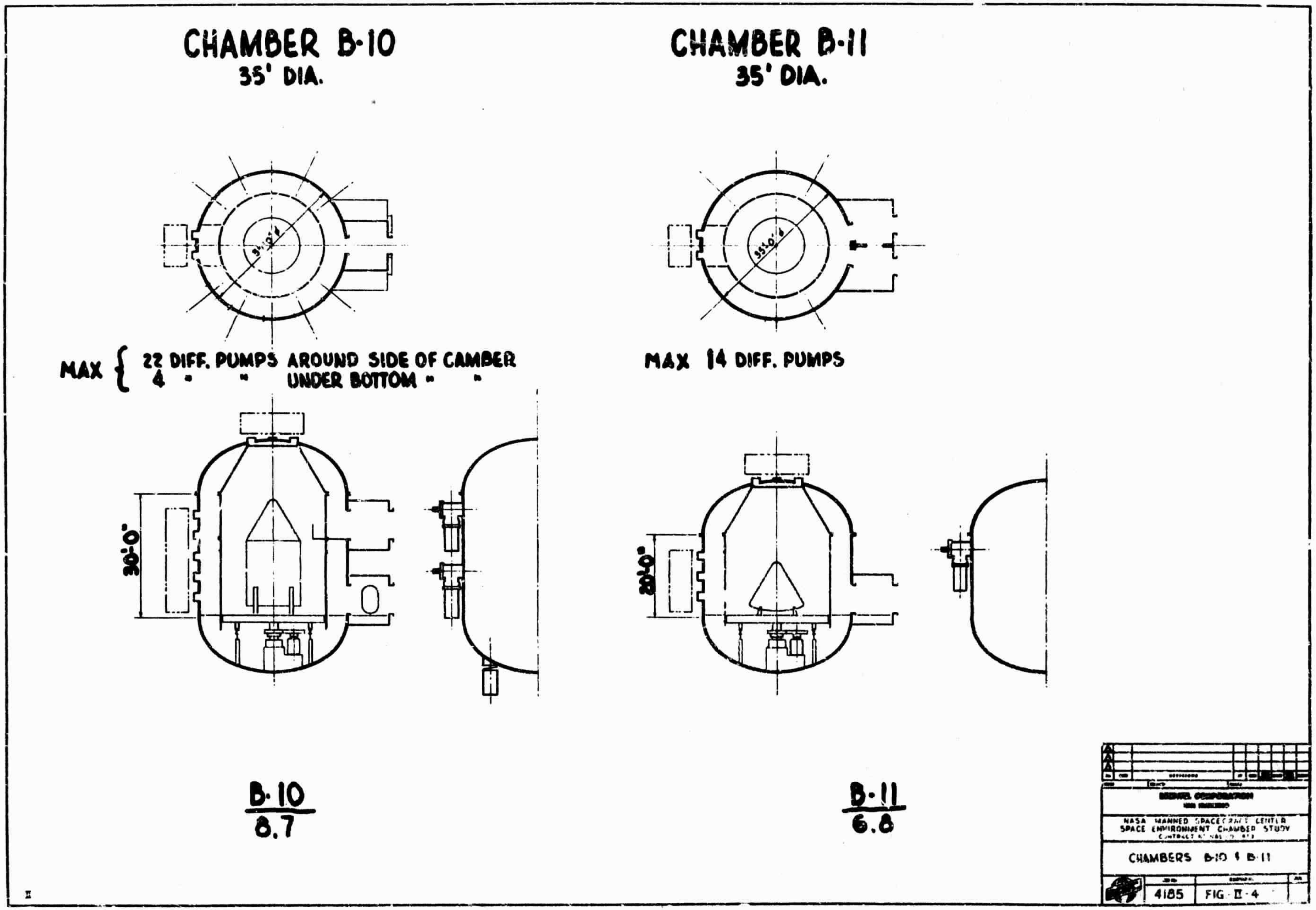
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

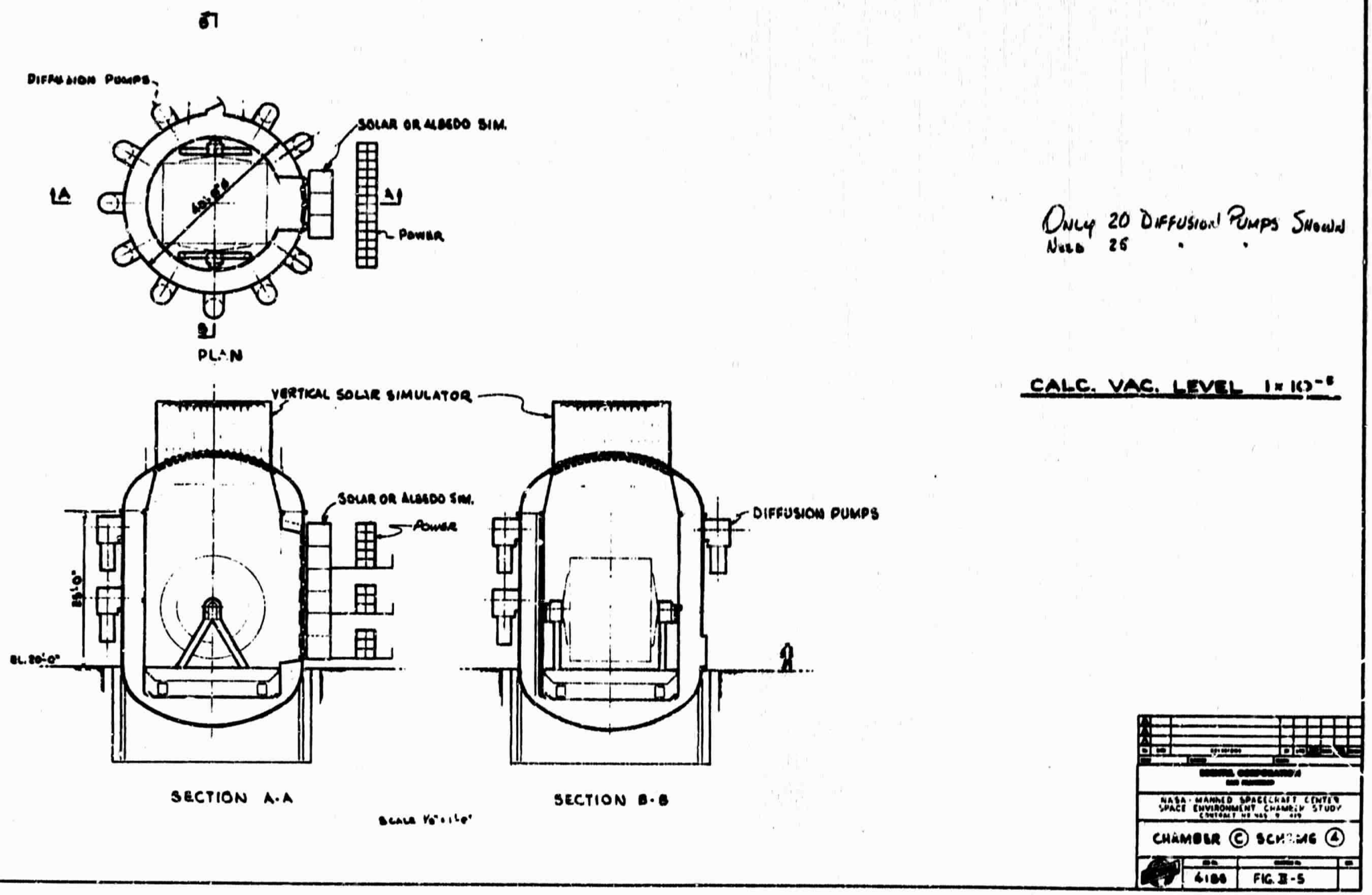
CHAMBER B - SCHEME 6

4185

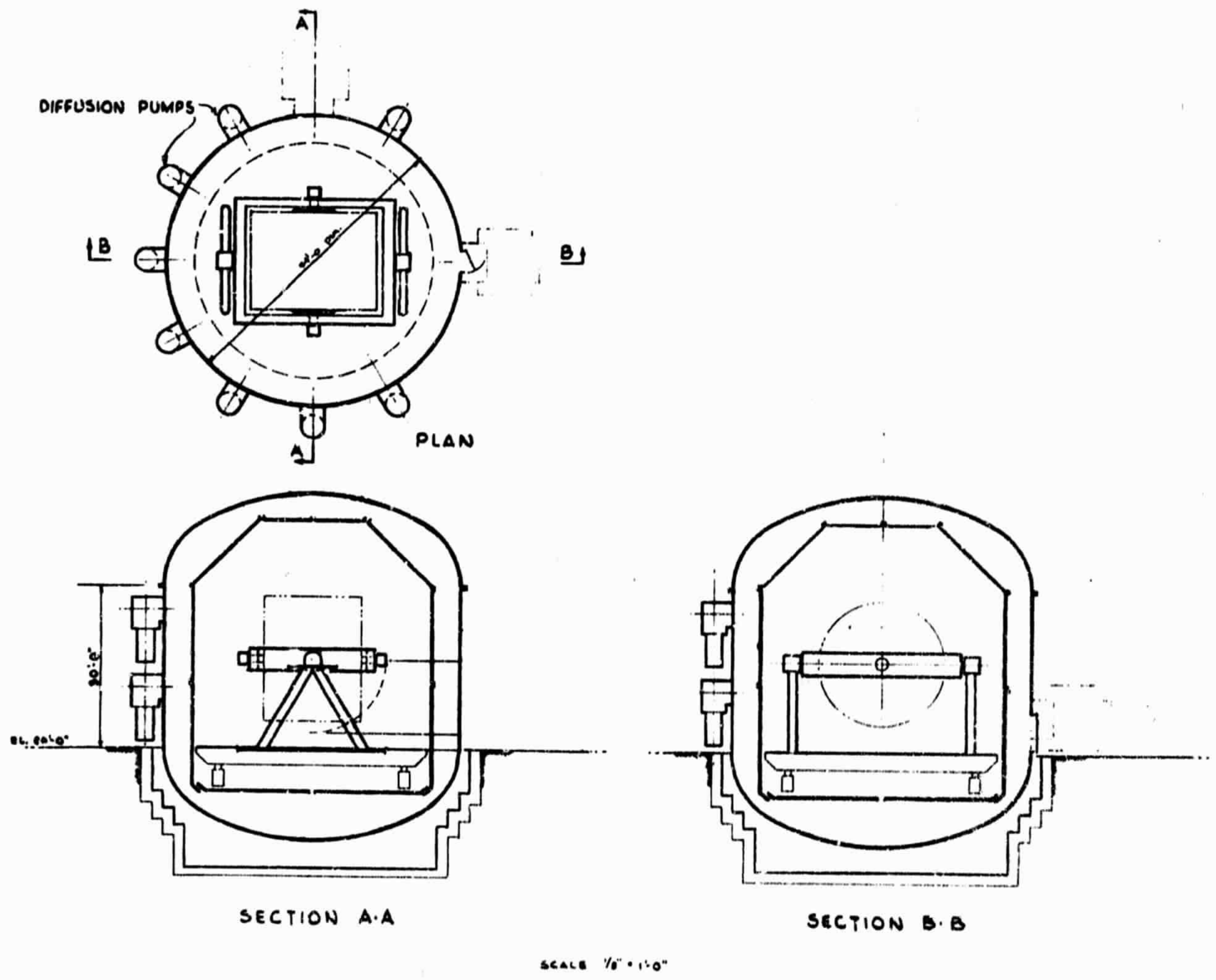
FIG.-II-3

II


CHAMBER B-10
35' DIA.
CHAMBER B-11
35' DIA.
MAX { 22 DIFF. PUMPS AROUND SIDE OF CAMBER
4 " UNDER BOTTOM " "
MAX 14 DIFF. PUMPS
30'-0"
20'-0"
B-10
8.7
B-11
6.8
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CHAMBERS B-10 & B-11
4185
FIG II-4


DIFFUSION PUMPS
SOLAR OR ALBEDO SIM.
POWER
PLAN
VERTICAL SOLAR SIMULATOR
SOLAR OR ALBEDO SIM.
POWER
DIFFUSION PUMPS
EL. 20'-0"
SECTION A-A
SECTION B-B
Only 20 Diffusion Pumps Shown
Need 26
CALC. VAC. LEVEL 1×10⁻⁸
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CHAMBER (C) SCHEME (4)
4186
FIG. II-5

II



NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

CHAMBER (C) SCHEME (5)

4185 FIG. II - 6

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SECTION III
VESSELS

1.0 General - The portion of the design study directly concerned with the vacuum chamber was separated into the following subjects:

a. Materials
b. Chamber Shape
c. General Structural Considerations

2.0 Materials - Four basic structural materials were considered for use in these chambers. They were carbon steel, stainless steel, stainless steel clad on carbon steel, and aluminum. The bases for comparative evaluation were:

a. Surface characteristics - gas desorption and cleaning
b. Thermal characteristics:
    1. Coefficient of thermal expansion
    2. Thermal absorptivity
    3. Low temperature ductility
c. Cost

2.1 Surface Characteristics - The influence of the structural material upon the attainable vacuum is dependent upon the exposed surface. This surface must be maintained free of gross oxide accumulation if excessive bakeout or cool-down of the chamber is to be avoided upon upgrading of the required vacuum. Such an accumulation presents a very large absolute area for adsorption of atmospheric gases and makes it difficult to remove surface contaminants.

The candidate materials may be differentiated by noting that the oxidation of carbon steel is progressive and continuous in a variety of environments. Conversely, austenitic stainless steels and most aluminum alloys form thin, tightly adhering oxide layers which generally prevent progressive deterioration of the surface.

Investigation of the effect of using normal mill finish stainless steel plate for the chamber walls shows that this approach is feasible. A typical initial rate of gas and water vapor desorption is expected to be approximately 0.25 torr lit/sec for Chamber A. At least 90% of the desorbed gas will be water vapor which will be pumped by the 100°K heat sink panels. Even if this pumping of the water vapor were not

possible, the contribution of the desorbed gas to the total gas load would be insignificant at the specified vacuum level of 1×10^{-5} torr.

Analysis of the pumping capacity of the heat sink panels, cryopumps, and diffusion pumps indicates that the empty chamber will have an ultimate vacuum capability of 1×10^{-7} torr or better, assuming there is no gas load from test articles. It is likely that other chamber components such as the large valves for the repressurization system will be much larger gas sources than will desorption from the chamber walls.

It is feasible to use low vapor pressure paints in a 1×10^{-3} torr environment. This plan would greatly facilitate the cleaning of gross contaminants such as oil and grease from a carbon steel wall and protect it against excessive oxidation. However, the use of carbon steel and paint for the vacuum surface of the chamber would limit upgrading the vacuum capabilities.

2.2 Thermal Characteristics

2.2.1 Coefficient of Thermal Expansion - This consideration is not important unless appreciable changes in shell temperature are encountered. Such changes could result from outbaking, external direct cooling, or indirect cooling resulting from the use of external shell insulation. Since none of these temperature effects are necessary to attain the specified vacuum levels in Chambers A and B, thermal expansion is not important.

The temperature changes resulting from cryogenic leaks should be sufficiently localized as to have no general effect on the chamber dimensions.

2.2.2 Thermal Absorptivity - The thermal radiation from the structural walls of Chambers A and B to their respective heat sinks will be influenced by the absorptivity of the surfaces. The absorptivity of each metal appears to be reasonably constant over the range of wave lengths that will exist with the structural wall essentially at ambient temperature.

The range of absorptivity (α) to be expected are:

Material	Absorptivity
Carbon Steel (CS)	0.8 to 1.0 (0.9)
Stainless Steel (SS)	0.12 to 0.20 (0.15)
Aluminum (Al)	0.03 to 0.07 (0.05)

If ϵ_s is the emissivity of the heat sink (~ 0.10), ϵ_w is the emissivity of the structural wall, and the wall and heat sink temperature do not vary,

$$q = \frac{K}{\frac{1}{\epsilon_s} + \frac{1}{\epsilon_w}} \qquad \frac{K}{10 + \frac{1}{\epsilon_w}} \qquad (\epsilon = \alpha)$$

where "q" is a relative index of radiant heat transfer. If q_{cs} is set at unity:

Subscripts

$$q_{cs} = 1.0$$
$$q_{ss} = 0.645 = q_{cl}$$
$$q_{al} = 0.348$$

(cs = Carbon Steel
(ss = Stainless Steel
(cl = Stainless Clad carbon steel
(al = Aluminum

Thus, it is apparent that the heat load from the chamber wall to the refrigeration system, in the absence of a thermal radiation shield, can be significantly reduced by using stainless steel, clad, or aluminum.

2.2.3 Low Temperature Ductility - Since these chambers are to be neither directly cooled nor insulated on the outside, this consideration is of importance only if it is assumed that cryogenic leaks could be large enough to produce cooling of significant areas of the shell. Since even small leaks cannot be tolerated in a high vacuum vessel, the cryogenic piping will be heavier than required by stress considerations to insure tightness of the welds. Thus, there should be little danger of cryogenic leakage except as might result from damage to the panels during emergency repressurization, in which case the LN_2 will be dumped externally, whether or not leaks occur, minimizing the spillage. However, the use of cryogenic fluids to simulate fuel loading in the vehicles in Chamber A introduces a real danger of gross flooding; hence a structural material exhibiting adequate low temperature notch ductility should be used.

2.3 Cost - The influence of a material on the cost of a chamber is reflected by the material cost, fabrication costs, and construction costs. The approximately base cost of each of the candidate materials is tabulated below. The effects of cost differentials in fabrication and

construction are reflected in the cost index figures in the summary tabulation, Section 5.0.

Material	Approximate Cost ($/Ton)		
	t = 5/8"	t = 7/8"	t = 1-1/8"
A201 Gr. B	160	160	160
Type 304 SS	1200	1200	1200
A201 Clad	1000	880	840
Aluminum	1150	1150	1150

2.4 Summary Evaluation - The following table rates the performance of the candidate materials according to categories of excellent (E), good (G), average (A), poor (P) and unsatisfactory (U).

	CHAMBER A				CHAMBER B			
CRITERIA	C.S	S.S	Clad	Al	C.S	S.S	Clad	Al
Surface Characteristics	U	G	G	E	A	G	G	E
Thermal Characteristics	U	G	U	E	A	G	S	E
Cost	E	A	A	A	E	A	P*	A

* Thinner plate than evaluated in Section 2.3

2.5 Recommendation - The considerations of potential cryogenic spillage within Chamber A and of the relative cost of thin plate as is used in Chamber B indicate that both chambers should be constructed of stainless steel plate. It will be satisfactory to use carbon steel external stiffeners because the low cross sectional area of the webs compared to the large area exposed to the warm atmosphere prevents dangerous chilling of the stiffener. This performance was demonstrated in recent tests which provide the basis of a paper in preparation for the American Welding Society, October 1962.

3.0 Chamber Shape - Various vessel shapes (Fig. III-1) were studied to determine the combination of shell and head configurations that best satisfied the fol' wing criteria:

a. Close conformation to space requirements
b. Optimum accommodation of the large door
c. Minimum building requirements
d. Ease of mounting appurtenant equipment (diffusion pumps, solar simulators, etc.)
e. Future expansion capability
f. Minimum cost (basically, minimum weight)

3.1 Close Conformation to Space Requirements - The practical degree of conformance to the test article envelope was limited by the necessity for allowing room for a vehicle mount or table, cryogenic panels, dispersion of solar simulator radiation, and maneuvering the test article during entry and exit. The latter is of primary importance in Chamber A, for which the specified maximum vehicle length controls the minimum chamber diameter. Entry and exit of the test article for Chamber B is provided by making use of a full diameter, removable top head.

The cylindrical shell provides the closest adherence to the specified test article dimensions for Chamber A because of the cylindrical shape of the test vehicle.

It was found that the cylindrical portion of the chamber could be made shorter than the vehicle height, and still maintain the required clearance, by taking advantage of the conical shape of the command module. Thus the overall length of the chamber was maintained constant while D/4 and D/3 ellipsoidal heads, and a hemispherical head, were evaluated as to cost and adaptability to the other criteria.

The choice of Shape B-11 as the reference for Chamber B led to consideration of a full sphere as an alternate. Although this shape appeared attractive from the point of view of the chamber alone, investigation of other criteria such as minimum building requirements and ease of mounting appurtenant equipment resulted in the termination of this portion of the study.

3.2 Optimum Accommodation of the Large Door - Early studies of possible configurations for the large door were made. It was readily apparent in the study of non-circular openings that problems in reliability would result from the need for field machining a large flange of compound curvature as well as the uneven operating load

distribution around such a flange. The lack of such problems for a circular door, when added to obvious savings in materials cost, led to exclusive recommendation of circular openings for test article entry and exit.

The large opening considered in this study varied slightly in size depending upon the orientation of the test vehicle during passage and on the length of the particular vehicle module considered for each chamber.

There are two preferred methods of locating a large opening in a chamber. The first is to locate the opening radial to a spherical shell so that the edge of the opening lies in a single plane. This was the prime incentive for the study of multi-spherical Shape A-3, which was eliminated by failure to satisfy other criteria. The second method is to make the opening coaxial with a cylindrical shell. This either makes the opening radial to the head (similar in advantages with the first method) or provides a full-diameter, removable cover. This method is used in the final Chamber B as well as in Chamber A-2, which was discarded for reasons of excessive building height and size.

Accommodation of the large opening radial to a cylindrical shell can be accomplished satisfactorily so long as the opening to be reinforced does not exceed approximately 90^{o} of arc on the cylindrical surface. The analysis of such an opening and the structural details to provide such non-planar reinforcement as is required makes this type of opening more costly than either of the two preferred methods. Additional considerations, such as the method of handling and erecting the reinforcement in one piece, indicate that the 40 ft diameter opening is the maximum feasible size for Chamber A if the opening is made in the cylindrical surface.

3.3 Minimum Building Requirements - Satisfaction of this criterion is closely allied to the criterion of close conformance to vehicle size. It follows that the more closely a shell conforms to the minimum space requirements, the smaller it will be. An additional facet of this criterion, however, is the effect of overhead entry of the test article into Chamber A. Chamber A-2 was investigated to determine the feasibility of this approach. It was found that an additional seventy feet of building height would be required to provide for the vehicle handling. In addition, extra lateral space would be required for storage of the cover during test-article handling. For these reasons, this concept of vehicle handling was discarded for Chamber A.

The overall height of Chamber B is such that overhead handling of the cover does not greatly influence the building structure.

3.4 Ease of Mounting Appurtenant Equipment - Equipment to be mounted on the chamber wall includes diffusion pumps, solar-simulator lens ports, solar simulator mounting framework, and viewing ports. It appears that a nominal cost saving can be made by making all the penetrations of each type and all the solar simulator mounting details identical. Another savings results from the standardization of solar simulator lens systems which will make them interchangeable. This interchangeability should provide the greatest flexibility of adaptation to various radiation area requirements with a minimum of initial capital equipment.

The cylindrical side walls of Chamber A1, A2, A12, A16, B10 and B11 best satisfy this requirement. The chambers having spherical side walls require that the lens systems vary between each level. This criterion was instrumental in the choice of a cylindrical chamber.

3.5 Future Expansion and Upgrading Capability - The technical guidelines require that provision be made for future expansion of the chamber, wherever practical. The probability of creating leaks, combined with the great weight of the top head, makes it impractical to incorporate details into Chamber A that will permit simple insertion of a cylindrical section required to increase the height of the vessel.

The height of Chamber B can be increased by adding a cylindrical section between the top flange of the presently proposed cylinder and the removable top head. The effect of this extension on the required height of the building also must be evaluated.

So long as a suitable plate material is used, the chambers will not be the controlling factor for obtaining higher vacuum.

3.6 Minimum Cost - It can be misleading to evaluate separately the minimum cost of any component of the facility without regard to secondary cost effects on allied components. For this reason the minimum cost chamber cannot necessarily be considered to be the best economic choice and no direct comparison of cost indices are presented for all shapes. Total-cost comparisons are presented, however, for the final chambers in Section 5.0.

Advantage was taken of every opportunity to use less costly details and shapes that did not have deleterious secondary effects on the cost of other components of the facility. An example of this practice is the use of hemispherical heads wherever practical (i.e., top head of Chamber A). This head produced only nominal increases in building costs, yet yielded a considerable saving over a D/3 or D/4 ellipsoidal head.

3.7 Recommendation - It is recommended that shapes A-12 and B-11 be selected as affording the best satisfaction of the above criteria.

4.0 General Structural Considerations - Several different approaches were made in the structural design of the vessel wall with due consideration given to safety, reliability, and cost. The effect of wall configuration, codes, penetrations, and supports on these criteria were studies.

4.1 Wall Configuration - The chamber wall must be capable of safely withstanding an external pressure of 15 psi. In addition, loads resulting from the heat sinks, cryopumps, diffusion pumps, vehicle handling, and solar simulators must be considered. Three (3) wall configurations were studies; namely, single wall unstiffened, single wall stiffened, and double wall.

A double wall vessel offers the attractive feature of a guard vacuum between the two walls. However, it also offers the extreme disadvantage of almost twice the cost of a single wall vessel for vessels of the size considered in the study. Since the guard vacuum is not required to obtain the vacuum level desired within the chamber and cost is a primary consideration, studies of a double-wall chamber were not pursued.

The wall thickness required for a large diameter, single wall, unstiffened vessel will be much greater than that required for a stiffened vessel. As discussed elsewhere, the vessel wall will be either stainless steel or stainless clad-carbon steel. The stiffeners on a stiffened vessel can be made from carbon steel, however, if they are located on the outside of the vessel. Using this construction, the shell material is replaced by stiffener material which costs about one eighth as much. Furthermore, the total material required for a stiffened vessel is normally less. Preliminary cost figures indicate a stiffened vessel is much more economical than an unstiffened one.

There are many combinations of plate thickness and stiffener spacing which can be used for a stiffened vessel and which will offer a comparable degree of safety and reliability. The minimum shell thickness should provide a factor of safety of 2 against buckling under axial load. For vessels constructed of a solid stailess steel or a stainless clad carbon steel wall with carbon steel stiffeners, the thinnest possible shell will usually cost the least. Stiffener spacing of 60 inches for Chamber A is recommended to conform to the spacing of the solar simulator ports.

4.2 Codes - The vessel design does not necessarily conform to any code, although the rules in Section VIII of the ASME Code were followed where practical. Because this code was not intended to include vacuum vessels, many of the rules are unduly restirctive. A detailed study and recommendation on the sections of the code which should be considered as inapplicable was submitted to MSC during the study (CTN-5).

The design of the double curvature heads are based upon formulas developed by CB&I through full scale testing of stiffened sphere . These heads are designed to be as safe as an unstiffened head designed by the ASME Code procedures.

4.3 Penetrations - It is desirable that all openings be circular where practical since the cost of the reinforcement for the opening and the machining of the flanges will then be held to a minimum. Insert type reinforcements should be avoided where pads or external stiffeners can be used since they would necessarily need to be solid stainless or stainless clad carbon steel. A pad plate or structural type reinforcement of carbon steel will provide minimum cost. For very large openings, reinforcement must be provided which will offer the required edge stability as well as proper stress level.

4.4 Supports - The chambers under study offer no unusual support problems. It is expected that the walls will remain at essentially ambient temperature; thus there will be very little thermal movement. Structural columns attached to the shell at the lower tangent line are recommended. The lower end of the columns should terminate with a standard base plate which is anchored to the foundations by nominal size anchor bolts. Sway bracing is recommended in alternate bays to prevent side sway which might occur from wind loads on the vessels during the construction period. After the building is completed these may be removed if desired.

5.0 Summary Tabulation & Comparative Costs - The following table summarizes the results of the vessel studies.

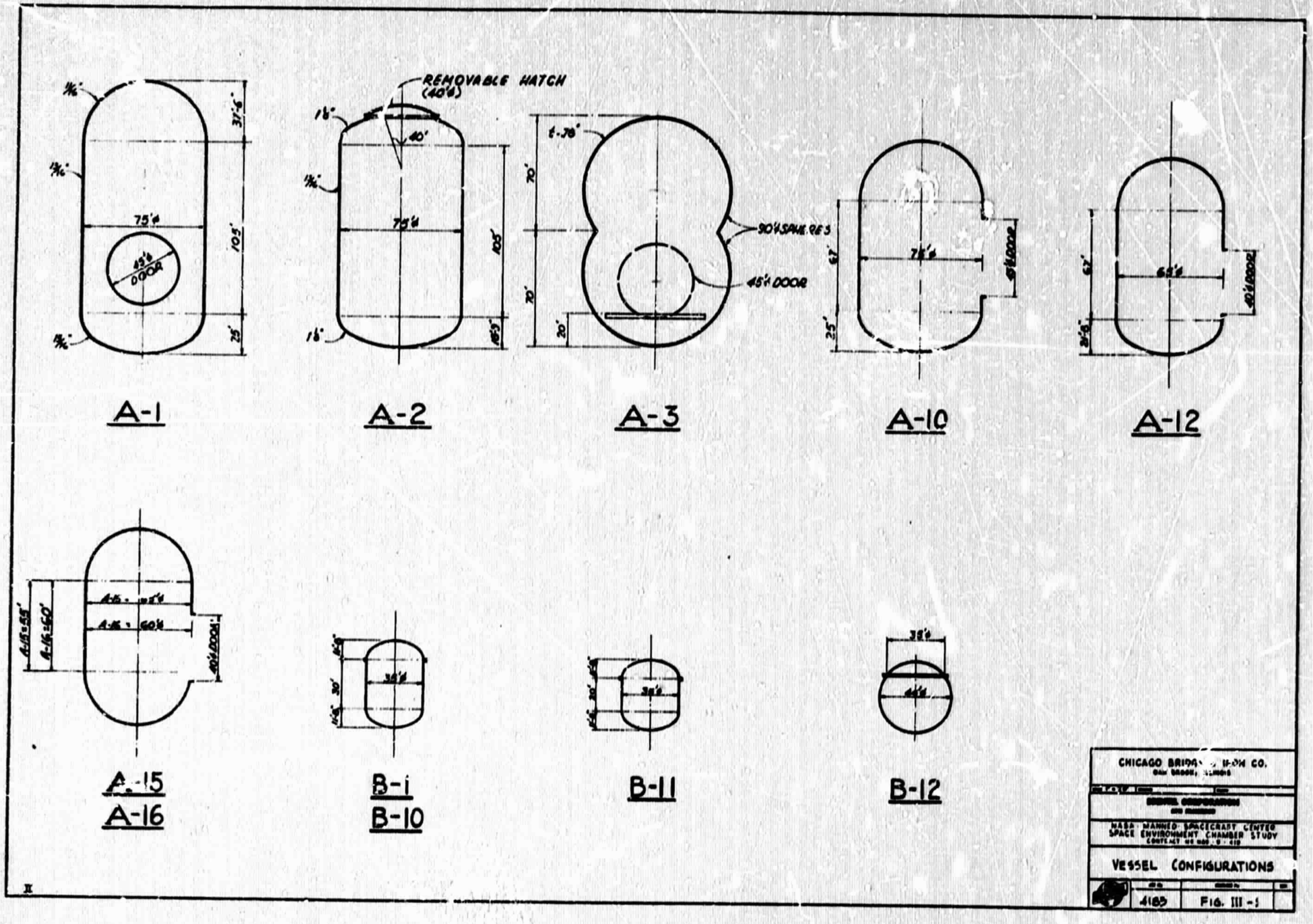
CRITERION \ CHAMBER	A-2 (1) 75'Ø cyl	A-3 (1) multi-sphere	A-10 (1) 75'Ø cyl	A-12 (2) 65'Ø cyl	A-15 (2) 65'Ø cyl	A-16 (2) 60'Ø cyl	B-10 (3) 35'Ø cyl	B-11 (4) 35'Ø cyl	B-12 (4) 44Ø sphere
(1) Conformation to space requirements	G	P	G	G	G	E	G	G	P
(2) Accommodation of large door	E	E	G	G	G	A	E	E	G
(3) Minimum Building requirements	U	P	A	A	A	G	G	E	P
(4) Ease of Mounting equipment	G	U	G	G	G	A	G	A	U
(5) Future Expansion	A	P	P	P	P	P	G	G	A
(6) Cost: S.S.	-	-	34	21.5	22.0	20.0	7.7	7.2	-
Clad	-	-	-	20.8	-	19.4	—	-	-

(1) Vehicle size = 35'Ø x 105' long, with 60'Ø lunar supports
(2) Vehicle size = 25'Ø x 75' long, with 40'Ø lunar supports
(3) Vehicle size = 13'Ø x 24' long
(4) Vehicle size = 13'Ø x 14' long

6.0 Summary Recommendations

6.1 Chamber A - It is recommended that Chamber A be of shape A-12, that is, a 65 ft diameter cylinder having a tangent length of 67 ft with a hemispherical top head and a D/3 ellipsoidal bottom head. The shell and heads should be of stiffened plate construction with stainless steel plate and external carbon steel stiffeners. Vehicle entry should be provided through a 40 ft diameter opening located in the cylindrical shell.

6.2 Chamber B - It is recommended that Chamber B be of shape B-11, that is, a 35 ft diameter cylinder having a tangent length of 20 ft with D/3 ellipsoidal top and bottom heads. The shell and heads should be of stiffened plate construction with stainless steel plate and external carbon steel stiffeners. Vehicle entry shall be provided by making use of a full diameter removable top head.



REMOVABLE HATCH (40'ø)
75'ø
45'ø DOOR
31'-6"
105'
25'
40'
18'-3"
t-70'
70'
20'
90'ø SPHERES
45'ø DOOR
75'ø
67'
40'ø DOOR
65'ø
21'-6"
A-15 = 55'ø
A-16 = 60'ø
A-15 = 55'
A-16 = 60'
40'ø DOOR
30'ø
30'
38'ø
44'ø
A-1
A-2
A-3
A-10
A-12
A-15
A-16
B-1
B-10
B-11
B-12
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VESSEL CONFIGURATIONS
4185
FIG. III-1

II

SECTION IV
VACUUM SYSTEMS

1.0 General - The pressure in a vessel will be reduced if the number of gas molecules which occupy the volume is reduced. This reduction in the number of free moving gas particles can be produced by any of the following methods:

a. Volumetric Transfer of gas molecules trapped in a pumping void into an area of higher pressure. This is the operating principle of:

1. Rotary pumps
2. Positive displacement blowers
3. Rotary vane pumps

b. Kinetic removal of gas molecules by collisions with high velocity surfaces or particles of a propelling stream. This is the operating principle of:

1. High speed centrifugal blowers
2. Axial blowers
3. Steam ejectors
4. Liquid stream
5. Diffusion pumps
6. Molecular drag pumps

c Immobilization of gas molecules by condensation from the gas phase to the liquid or solid phase. This is the principle used in:

1. Cryopumping
2. Low temperature adsorption

d. Immoblization of gas molecules by a chemical reaction forming solid or liquid compounds.

2.0 System Requirement - The vacuum systems for the facility complex must be adequate to perform two distinct functions:

a. Removal of the atmospheric constituents from the volume of the chamber and consequent reduction of the pressure from 760 torr to a level sufficiently low for the simulation tests to be conducted.

b. Removal of the gases, released from the test object, its accessories, vessel walls, and attendant personnel at a rate which will permit maintenance of the desired operating pressure level.

In addition, the various pumping equipment selected must be compatible with requirements of "man-rating and personnel safety" by being either inherently safe for such operation or by being capable of simple adaptation to render it "safe".

Various pumping devices on the market exhibit well known limitations of applicability in the range of 760 torr to desired operating level. This entire range, however, can be covered by sequential and/or parallel operation of two or more systems as outlined below. The systems must cover the "rough pumping" range (760 torr to approximately 3×10^{-3} torr), "diffusion pumping" range below 3×10^{-3} torr, and the "cryopumping" range below 1×10^{-4} torr. At pressures below 1×10^{-4} torr the diffusion pumping system and cryopumping arrays may be operated in parallel.

3.0 <u>Alternative Concepts</u> - A study of alternative concepts for pumping within the specified pressure ranges, was carried out, and reference was made to other technical reports published in recent years for a basis of comparisons applicable to the present task. The basic document reviewed was originally prepared for the U.S. Air Force, Arnold Engineering Development Center:

Technical Report - Phase I
Feasibility Study of Space Simulation Facility
Contract AF 40 (600)-852, Project No. 7776
Task No. 77794, NRC Project 40-1-035

A critical review and evaluation of this report, suitably updated, was made in the light of the present requirements.

Alternative concepts were studied for the roughing system and diffusion pump system, with particular emphasis on the selection of diffusion pumps, the applicability to the span of the pressure range involved, and the requirements dictated by "man rating".

Final evaluation and recommendations are based on considerations of :

a. Initial cost
b. Ease of operation and maintenance
c. Economy of utility requirements
d. Economy of space requirements and equipment location in relation to the space chambers.

Capacity selection was made to satisfy:

a. Desired pumpdown times

b. Ability of the system to attain desired pressure levels when handling specified leakage loads and an additional leakage allowance for virtual leaks, outgassing, etc.

4.0 Rough Pumping (760 Torr - 3x 10^{-3} torr)

4.1 Alternative Concepts - The following major types of pumps were reviewed:

a. Oil Sealed Rotary Vacuum Pumps
b. Positive Displacement Blowers
c. Rotary Vane Compressors
d. Multistage Steam Ejectors
e. Combinations Of A & B Preceding

4.2 Evaluation & Recommendation - Recommendations were made in the light of the criteria previously stated in conjunction with the desireability of furnishing of safety and "overlap" at the low end of the operating pressure range at the trasition to the diffusion pumping range. The recommended selection for this system is a multistage positive displacement blower cascade with an "oil sealed" rotary vacuum pump as the final stage. This arrangement has the following advantages over the other pumping means considered:

a. It best satisfies all "economy" considerations previously stated.

b. It affords exceptional "ease" of operation and requires fewer operating and maintenance personnel.

c. It is relatively simple and economical to adapt it with a "man rated" chamber.

This pumping complex will perform in such a manner that either Chamber A or B can be pumped to ultimate operating levels within the alloted time. It has the additional capacity necessary at the change-over to diffusion pumping.

5.0 Diffusion Pumping

5.1 Gas Loads - The following loads must be handled:

a. Release of gas from the test vehicle system

b. Release of gas from extravehicular suits of attendant personnel within the test chamber

c. Virtual leakage or gradual release of gas from the structure of the vehicle (honeycomb), its accessories, supports, etc.

d. Outgassing from the structural surface materials of the vehicle, especially in the solar beam.

e. Outgassing of materials of the space chamber, its internal mechanisms, and devices.

f. Actual leakage across seals, gaskets, feedthroughs, valves, and other connections.

For the pressure levels desired in Chamber A and B the significant amounts of gas will be contributed by the test article, space suits, and virtual leaks. Contributions from outgassing may be considered insignificant by comparison. Contributions from actual leaks can, by suitable procedures of design and fabrication, also be reduced to very low levels. For the purpose of pump selection the total gas load was assumed to result from sources 'a' through 'd'. Its value is based on the specified leak for 'a' and 'b' plus an allowance equal to these for the contribution anticipated from other sources.

The effects upon chamber performance was investigated for a "virtual" leak in the chamber, such as the honeycomb structure of the vehicle. A mathematical analysis was made of the evacuation of a volume within which is located another volume communicating with the main volume by a low conductance passage, in the presence of a constant external leak (NTN-15). This work led to several very complex equations whose numerial evaluation could not be completed during the study. Consequently, it was not possible to derive the magnitude of an "allowance" in gas load to accommodate virtual leaks. The recommended pumping systems are based on an allowance of 100% of the known gas load to handle the load from virtual sources.

5.2 Alternative Pump Stations - The largest commercially available diffusion pumps were reviewed and evaluated in the light of the requirements and the following specific factors:

a. Stability of the pumping mechanism at pressure levels usually considered relatively high for this type of pump, i.e., low 10^{-3} torr region.

b. Low rate of back streaming throughout the pumping range, specifically during the formation of the vapor stream in the top jet.

c. Maximum pumping speed attainable in the low 10^{-3} torr and high 10^{-4} torr pressure ranges.

d. Optimum performance under load conditions in pressure regions normally considered for diffusion pumps, i.e., below (to 8×10^{-4} torr.

e. Ability to qualify under the requirements for "man rating and safety", inherently or with some modification or adaptation.

The studies showed that all of these desirable characteristics were not available in a single pump. Consequently, consideration was given to two types of diffusion pumps for the stations to be used.

1. Type A - A pump station primarily designed for operation in the pressure region of 3×10^{-4} torr and below. Such pump stations will evacuate the test chamber from a point at which the roughing system becomes marginal to a level where they can be augmented by another type of diffusion pump station. Such stations will exhibit all the desirable characteristics except optimum performance below 6 to 8×10^{-4} torr.

2. Type B - A pumping station exhibiting all the desirable characteristics below 6 to 8×10^{-4} torr.

The following criteria govern a recommendation to use a multiplicity of "single pump" stations:

(1) The need for large valves at the inlets to diffusion pump stations primarily for safety in "man rating" and (2) the necessary size of ducts between pumps and space chamber envelope to yield maximum "effective" pumping speeds at the chamber.

5.3 Number of Pumps

5.3.1 Station Type A - For both Chamber A and B calculations were made to determine the minimum number of Type A pumping stations so that the "critical transition pressure range" i.e., between the roughing phase and diffusion pumping phase of a pumpdown cycle, could effectively be bridged and the total desirable pumpdown time to operating pressure could be achieved.

It was determined that 4 Type A stations are required on each of the chambers to effectively achieve the object.

5.3.2 Station Type B - The number of pumping stations of Type B required to augment the capacity of the system at pressure levels of 8×10^{-4} torr and below was investigated for Chambers A and B considering the following:

Chamber A

a. Pump-down time required to lower the chamber pressure to 1×10^{-4} torr, at which point cryogenic pumping will commence, attaining the ultimate desired operating level of 1×10^{-5} torr in 24 hours.

b. A gas load imposed on the system equal to twice the specified leak of 13.8 torr lit/sec, or a total of 27.6 torr lit/sec.

c. Past experience with chambers of comparable type, size, and service utilizing similar pumping means or proportioning data from other, somewhat smaller facilities.

<u>Chamber B</u>

a. Pumpdown time required to lower the chamber pressure to 1×10^{-4} torr and resulting in an overall pumpdown time of 3 hours.

b. A gas load imposed on the system equal to twice the specified leak of 12.8 torr lit/sec or a total of 25.6 torr lit/sec.

c. Past experience with chambers of comparable size, type, and service requirements, utilizing similar pumping means or proportioning data from other, somewhat smaller facilities.

5.4 <u>Different Pump Types</u> - Commercially available diffusion pumps with nominal capacities of 30,000 lit/sec and larger were investigated to ascertain their suitability for use as Type A and Type B pump stations. The recommendations are as follows:

1. Type A-NRC Model H32-30,000 or equal. This pump has a peak speed of 30,000 lit/sec and shows pumping stability at pressures of 10^{-3} torr and above. The pumping speed plateau extends over the entire diffusion pumping range necessary for Chambers A and B. The pump can be used with fluids selected on the basis of "man rating" considerations.

2. Type B-NRC Model HS 35-50,000 or equal. This pump has a peak speed of 50,000 lit/sec at pressures of 4×10^{-4} torr and below. The pumping speed plateau extends over the entire diffusion pumping range necessary for Chamber A and B. It can be used with fluids of "man rating" considerations.

5.5 <u>Attainable Pressure Level Versus Total Gas Load</u> - A determination of the attainable pressure levels was made on the basis of using 4 Type A stations augmented by an arbitrary number of Type B stations. The effect of supplementing or replacing these in part with cryopumping surfaces at pressure levels below 1×10^{-4} torr was also evaluated. The results are shown graphically for Chambers A and B on Figs. IV-1, IV-2 and IV-3.

5.6 <u>Oil Selection</u> - The problem of selecting suitable working fluids which will satisfy the requirements for diffusion pump operation on a "man rated" chamber and the incumbent safety aspects, was intensively studied. (NTN-18)

Many of the conventional ester type fluids, such as "Octoils", and hydrocarbon fluids, such as "Convoils" etc., used for high vacuum applications, meet many of the desirable qualities for normal diffusion pump application but do not exhibit the best heat stability or oxidation features. They cannot tolerate exposure, when hot, to pressures above a few hundred microns for any period of time without deterioration and decomposition. On this basis they appear unsuitable for our consideration.

The silicone fluids and polyphenyl ethers which have recently emerged in the field, show the greatest promise for this application from theoretical considerations of their properties.

In the absence of sufficiently conclusive evidence that safe operation can be achieved with the fluids selected, maximum safety measures should be planned. This statement gives due consideration to the maximum hazard conditions that may arise during emergency repressurization.

The following recommendations are made:

1. A silicone fluid, such as DC704, or a Polyphenyl ether, such as Monsanto OS-124 should be used.

2. A diffusion pump should be selected in which there is no "superheating" of the fluid or vapor. Both the liquid and vapor in such a pump will operate at a temperature below the "flash point" of the fluid.

3. A quick acting isolation valve should be installed above each diffusion pump capable of closing within 5 seconds. Valve closure is to be initiated at the same time that emergency-repressurization procedures are triggered.

4. Nitrogen should be admitted between the pump and duct valve at the beginning of emergency repressurization. (NTN-18).

5. Electrical power supply to the pump heaters should be interrupted and water cooling of the pump boiler, by the quick-cool coils, should be initiated.

5.7 <u>Duct Valves</u> - For reasons explained above, the use of duct valves ahead of the diffusion pumps is recommended.

Several types of vacuum valves were investigated on the basis of:

1. Suitability for operation at the desired vacuum levels
2. Commercial availability and cost
3. Effect of reducing the pumping speed of the diffusion pumps by introducing appreciable impedance into the duct.

4. Ability to effect a quick closure under emergency conditions without undue damage to the valve mechanism and seals.

5. Convenience of installation and operation

6. Additional benefits gained, (Individual pump performance checking maintenance or replacement during a prolonged test run of the facility.)

The basic types of valves reviewed were:

1. Slide or gate
2. Butterfly and swing gate
3. Right angle poppet

All types are to be power actuated remotely controlled. The study shows that the right angle poppet type valve by far scores highest on all counts and it, therefore, is the recommended type for use with pump stations. Type A and Type B.

An evaluation of conductance for sizes from nominal diameters of 32 inch to 48 inch was made to determine the effective pumping speed resulting from the selected pump valve combination. Calculations were made to determine the mode of gas flow through "long cylindrical" ducts. For the large diameter valves under investigation, it was found that the flow of air (20°C) is viscous to the middle 10^{-4} torr range and that molecular flow commences in the low 10^{-5} torr region. Various combinations of valve body duct diameter and valve seat diameter were investigated to determine their most favorable combination. Factors considered were:

1. Conductance and resultant "effective pumping speed" of a diffusion pump station (Type A and B)
2. Component Cost

The cost of the operating mechanisms of all sizes investigated remained essentially unchanged. The design of the mechanism is governed by safety considerations of "man-rating" (Section 5.6). The difference in costs of the valve bodies for the range of sizes investigated is reflected primarily in the material content and has a lesser influence on the overall component costs. The recommended component, on the basis of the above, is a 48-inch diameter body and duct combined with a 42 inch diameter valve seat.

6.0 Cryopumping - Various designs of cryopumps investigated during the study are described in Section VI and are depicted in Figs. VI-1, VI-2, and VI-3.

The recommended arrangement (Fig. VI-3) has the bighest pumping rate, 2.7 lit/sec cm^2, with the principal gas load consisting of 50% O_2 - 50% N_2 and with the heat sink panels at a maximum temperature of $100^{o}K$. Fig. IV-2 show the vacuum levels attainable as a function of the installed cryopumping area for various gas loads. These vacuum levels are based on earlier concept (Fig. VI-1, arrangement No. 1) having a reduced pumping speed (2.2 lit/sec cm^2). The curves, however, may be used for either configuration by properly adjusting the area so that the product of area and unit speed is the same for both configurations.

7.0 Personnel Lock Pumping System - The effect of personnel lock pressure level on equilization pressure levels, when a lock is opened to the chamber, was investigated (NTN-28). Attainable pressure levels in man locks using different pumping means were also examined. The optimum selection is a mechanical vacuum booster cascade resulting in sufficiently low lock pressure levels (with 2 extravehicular suit leakages) to produce very small temporary pressure surges in the main chamber upon opening of the communicating door.

The following table illustrates the effect of opening the door between a manlock and the main chamber.

	Pressure (torr)		
Chamber	Chamber	Manlock	Equalization
A	1×10^{-5}	3×10^{-3}	2.5×10^{-5}
B	1×10^{-4}	3×10^{-3}	2.3×10^{-4}

8.0 Economic Optimization - A study was made to determine the economics of furnishing capacity for handling the total gas loads of Chamber A and B at pressure levels of 1×10^{-4} torr and below. A pressure level of 1×10^{-4} torr is considered to be the upper limit for continuous cryopump operation. It was determined, that to reach a pressure of 1×10^{-4} torr, a minimum number of diffusion pump stations is required to afford an overall facility pumpdown within the alloted time for the respective chambers. The need for a minimum number of diffusion pump stations (Type A) on Chambers A and B is discussed in Section 5.3.1. The need for a minimum number of diffusion pump stations (Type B) for effective pumping at pressures below 8×10^{-4} torr is discussed in Section 5.3.2.

The minimum number of diffusion pumps is found to be:

Chamber A: a total of 14 diffusion pump stations (4-Type A plus 10 - Type B).
Chamber B: a total of 12 diffusion pump stations (4-Type A plus 8 -Type B)

The attainable pressure levels, by the addition of further diffusion pumping stations or alternatively, by supplementing the minimum number of pumping stations with cryopumping capacity, is discussed in Section 5.5 and illustrated on Figs. IV-1, IV-2, and IV-3. Figs. IV-1 and IV-2 also relate the pumping speed to the installed costs for diffusion pumping and cryogenic pumping respectively.

Based on these studies, it is concluded that for operation below 1×10^{-4} torr, it is more economical to supplement the minimum number of diffusion pumps with the addition of the necessary area of cryopumping (20°K) surfaces rather than by additional diffusion pumps. The following recommendations constitute the optimum combination of pumping means:

Chamber A (Desired Operating Pressure level 1×10^{-5} torr). The minimum number of diffusion pump stations required (14) should be supplemented by 1400 ft^2 of 20°K cryopumping surface at an estimated pumping speed of 2.2 lit/sec cm^2. (Subsequent modification of the conceptual design indicated that the same pumping rate can be achieved with 1180 ft^2 of surface having a unit speed of 2.7 lit/sec cm^2.

Chamber B (Desired operating pressure level 1×10^{-4} torr) — The pumping capacity required be furnished by diffusion pumping stations only.

9.0 Leak Detection

9.1 Sources of Leaks - The following sources of leakage must be considered:

1. Welded joints.
2. Major chamber penetrations, such as access ports, pumping ducts, manlock ports.
3. Chamber feedthrough penetrations for cryogenic services, electrical and instrumentation services, motion devices and accessory devices such as viewing ports and solar simulation lens optics.

4. Gasket and Seals.

5. Chamber cryogenic system components including LN_2 cooled heat shields and thermal sink, helium cooled cryopumping panels and all associated piping.

For the purpose of this phase of the study, leakage from the vehicle and its attendants has been disregarded, as these will not be present during facility construction.

9.2 Species of Gas - The primary species of gas which may enter the chamber from the sources detailed above will have an appreciable effect on the analysis of the leak detection requirements for the space chambers and the resultant recommendations. This is of primary importance in the case of Chamber A, which contains helium cooled cryogenic pumping panels.

The gases potentially contributed will be:

a. Sources (1) through (4).
Atmospheric air containing N_2, O_2, Trace H_2O, helium and other minor constituents.

b. Sources (5)

a. Liquid nitrogen cooled shields, heat sink & piping-N_2.
b. Helium cooled cryopump panels & piping -He.

9.3 Basic Considerations - The detection of leaks from equipment internal to the chamber will require the establishment of fairly complex procedures involving "sniffing" and "gas probe" techniques, possibly on successive stages, using a halogen sensitive detector followed by a mass spectrometer type helium sensitive instrument. The following recommendations are made:

a. Cryogenic Panels - Leak testing panels and as much of the associated pipe work as possible must begin before installation. Panels should be strong & small enough to retain leak tightness during installation after a "ground" test. Consideration should be given to leak testing each panel on the ground under cryogenic conditions. This will permit detection of "cold leaks" which may appear due to cryogenic temperatures.

After installation each zone of cryopanels must be carefully checked by evacuating it, connecting it to a mass spectrometer and probing externally with helium gas. For this check only new welds or points suspected of damage will need to be tested.

b. <u>Vacuum Chamber</u> - In view of the foregoing, it is essential to initially leak test the "empty" vacuum chamber by suitable techniques. The size of the vessel (specifically Chamber A), its construction details, accessibility during fabrication and the magnitude of leaks which ultimately must be found were examined. Considering all factors, the use of a "vacuum-box" to initially examine portions of the chamber for leakage during the construction phase was discounted.

To be of value, the vacuum box technique would require operation at diffusion pump pressure levels using a leak detector on the backing line of the box pumping system. The approach appears undesirable in the light of problems of accessibility, test gear manipulation and sealing of the box to the areas to be tested. Further, techniques of space chamber fabrication have now reached a level where "gross leaks", such as could be detected by normal vacuum box operation, rarely occur.

It is therefore recommended that:

1. The chamber fabrication be completed prior to leak testing.
2. The chamber be "empty", so that chamber leaks are not "masked" by internally installed equipment (which may be leaking).
3. In the absence of natural compartmentation of the vessel or its wall, an external gas probe technique and/or "bagging" be used.
4. All feed throughs, cryogenic penetrations, access ports, lens and viewing ports be temporarily sealed off.
5. All vacuum seals on doors and similar major access penetrations be carefully installed.
6. The chamber be pumped with its own roughing and diffusion pump systems, which should be installed and made operative simultaneously with chamber completion.
7. Helium sensitive mass spectrometer leak detectors be used, connected to the backing space of one or more of the diffusion pump stations of the facility.

9.4 <u>Leak Rates and Testing</u> - The theory of applying a helium sensitive mass spectrometer for leak detection is amply described in: "Vacuum Equipment and Techniques", Chapter 5
A. Guthrie and R. C. Wakerling.
National Nuclear Energy Series
Division I, Volume I

A number of factors require examination:

a. Total Permissible Leak - The total diffusion pump speed available on Chamber A is approximately 3.5×10^5 lit/sec. It is reasonable to assume that at an operating pressure level of the chamber of 10^{-5} torr an allowance of about 10% be set aside to accommodate atmospheric leakage. However, in the light of future upgrading of the facility to lower operating pressure levels, an allowance of only 1% is suggested. The maximum permissible leak will therefore be

Speed x Pressure x Speed Allowance Fraction =

$$3.5 \times 10^5 \times 10^{-5} \times 10^{-2} \text{ torr lit/sec}$$
$$= 3.5 \times 10^{-2} \text{ torr lit/sec}$$
or 4.62×10^{-2} std cc per second

b. 90 Percent Response Time - This subject is analyzed by Guthrie and Wakerling in the above reference. It must be rapid, so that leak testing may proceed effectively and speedily and that the delay between detection of one leak and subsequent "clean up" of the system preparatory to seeking the next one is at a minimum.

With the installed diffusion pump capacity, this will not present a problem.

$$T = 2.3 \frac{V}{S}$$

Where T = Time required to reach 90 percent equilibrium

V = Volume Of Vacuum Vessel, liters
S = Speed of Diffusion Pump, lit/sec of air

For Chamber A:
V = 9.82×10^6 liters (approx.)
S = (14 diffusion pumps) = 3.5×10^5 lit/sec
T = 66 seconds (approx.)

(with one pump only, T = 15 minutes)

By suitable "sensitivity range" switching of the leak detector, further time can be gained, eliminating the need to await complete elapse of the 90% response time period.

c. Leak Detection Equipment - Mass spectrometer leak detectors primarily for use with helium, are made by a number of manufacturers. The three commercially available units that may be recommended for consideration are.

Veeco	MS-9
CEC	24-120
GE	M60

These units all have substantially the same "sensitivity" (1×10^{-10} atm-cc/sec), and the same discrimination against air (1 part in 10 million). It is strongly recommended that the units chosen be able to detect other gases including H_2, He^3, Ne, N_2, and that tuning for these gases be accomplished by an accurately calibrated dial that can quickly be reset for whatever gas is desired. The GE instrument is known to be so equipped, and presumably a similar arrangement is available or can be obtained optionally for the others. The convenience of a special selector switch by which the instrument can instantly be tuned may be found a necessity during operations. This is not a standard option but could be easily added as a modification by manufacturer. Apart from these points, a decision should be made on the basis of operating convenience, reliability, and ease of maintenance. Less sensitive mass spectrometer instruments are inadequate and should not be considered.

A reduction in sensitivity must be accepted when checking leaks in systems with large throughput. This reduction is determined by the relative pumping speeds of the forepump and of the leak detector.

d. Detectable Leak Size - For a single diffusion pump station Type B, holding Chamber A at a pressure of 1×10^{-5} torr, the total throughput is 2.5×10^{-1} torr lit/sec.

The maximum throughput which a typical mass spectrometer leak detector can handle while still providing "ultimate" sensitivity is about 10^{-3} torr lit/sec. Consequently the mass spectrometer only receives a portion of the helium diffusing into the chamber through a leak, by the ratio of the relative throughputs:

$$\text{Ratio:} = \frac{2.5 \times 10^{-1}}{10^{-3}} = 250$$

If the spectrometer has an ultimate capability of detecting 10^{-10} std. cc/second of helium, the smallest detectible leak is:

$10^{-10} \times 250 = 2.5 \times 10^{-8}$ Std. cc/sec.

or

1.9×10^{-8} torr lit/sec.

Comparing this with the total permissible leak rate of

4.62×10^{-2} Std cc/sec

or

3.5×10^{-2} torr lit/sec

it is seen that an adequate margin of sensitivity exists.

However, if leakage is such that one pump can hold the chamber at a pressure of 10^{-4} torr only, then by following the above steps it is found that the minimum detectible leak will be

1.9×10^{-7} torr lit/sec

When using all 14 pumps to hold the chamber pressure at 10^{-5} torr, this value becomes

2.6×10^{-7} torr lit/sec

In any case adequate sensitivity exists to detect small leaks and bring the total chamber leak rate to the specified level.

It is also seen that it is most desirable to carry out final leak test at as low a pressure level as is attainable with the minimum number of pumps, even though at early stages all pumps may be used to hold the chamber at relatively high equilibrium levels.

The preceding arguments apply equally to Chamber B, where however, the situation is eased by the relatively smaller chamber volume and high maximum connected pumping capacity.

10.0 Bakeout - Review of cur ent technology and published data indicate that for the pressure levels desired in Chamber A and B, the gas load from the inner chamber walls, etc. will have an insignificant effect upon facility performance. This conclusion is especially so in light of the relatively large gas loads contributed from other sources and for which the pumping systems must be sized. There is no indication for the need of accelerating the desorption of gases from the chamber walls, hence, provisions for baking Chambers A and B are not recommended.

11.[illegible] Normal Repressurization - It is recommended that the normal and emergency systems be kept entirely separate because performance of the safety system might be jeopardized by continued operation under normal conditions. A separate normal repressurization system lends itself to use in a chamber ventilation system and this arrangement is recommended whenever economies can be achieved. Normal repressurization can also be used as a follow-up to the emergency system so that after an emergency pressure rise to 5 psia, the chamber may be brought to atmospheric pressure at a slower rate through the normal system. Entering air for normal repressurization should be carefully filtered and dehumidified to protect both chamber and test article. Combining this system with a ventilation system will dictate the size and type of equipment to be selected. The normal repressurization system should be capable of raising the pressure from full vacuum to one atmosphere in approximately 3 hours, with dehumidified air. In semi-urgent situations, the normal repressurization system should be able to reach a pressure of 5 psia within 30 minutes using air which is not fully dehumidified.

It has been found in the operation of other space chambers that repressurizing with an initial blanket of nitrogen will reduce the time required for subsequent pumpdown. The physical mechanism of this phenomenon is not throughly understood but apparently the nitrogen "seals" or fills the pores of the chamber walls preventing other gases from achieving intimate contact with the metal. At the time of a subsequent test, the nitrogen is apparently more easily released. A nitrogen blanket is recommended for normal repressurization.

Each manlock will require a normal repressurization system. Such a system can easily be combined with a pressure equalization system between the lock and the chamber and an emergency repressurization system for the lock. Manlock ventilation, if required, can also be integrated into the total system; however, it is felt that no special ventilation provision will be necessary. The combined systems for the lock would require a remote operated vacuum valve between the chamber and the lock for pressure equalization and a similar valve between the lock and atmosphere for repressurization. During an emergency or under many normal operating conditions, the lock can be brought to atmospheric pressure or to vacuum conditions by manually opening the proper valve.

The doors between chamber and lock should be designed for positive pressure in both directions because the conditions of a fully repressurized chamber and an intermediate pressure in the lock may be encountered.

12.0 Emergency Repressurization

12.1 Oxygen Content - In order to attain the desired partial pressure of oxygen it is necessary that the emergency repressurization system use an enriched oxygen atmosphere. Because of lack of data on the long term effects of other gases only nitrogen has been considered as the diluent for oxygen. Aero-medical criteria make a 50% oxygen, 50% nitrogen mixture seem desirable and even higher oxygen enrichment would be advantageous.

Since an oxygen rich atmosphere entering diffusion pumps or backing pumps containing their normal oils would constitute a hazard, special oils may have to be used.

Either the try-cresyl phosphate type of pump fluids such as those marketed under the trade name of Cellulube or silicone fluids such as those marketed by Dow Corning are much less hazardous. All diffusion pump calculations reported for the study are based on the use of a silicone fluid. As an additional precaution, the oxygen rich repressurization gas should be kept out of the diffusion pumps by delaying its entrance into the chamber until the valves can be closed. All instruments and other apparatus within the test chamber must be oxygen rated, i.e., must be stable in oxygen rich atmospheres.

Even with the use of these precautions, the maximum safe O_2 content that will not cause hazards from fire and explosion must be established to determine the optimum oxygen enrichment. This may require that experimental testing be conducted prior to final design.

12.2 Source - Two of the basic methods for obtaining the desired O_2-N_2 mixture are:

1. a mixture of air and bottled oxygen
2. a mixture of bottled oxygen and bottled nitrogen

The use of air requires large intake filters, ducts, and valves. Although air will carry moisture into the test chamber, the quantities appear to be insufficient to justify air dryers. Furthermore, air is always available at 14.7 psia and its use improves the reliability of any repressurizing system.

As shown on the table below the use of a completely bottled system requires considerable added bottle cost which offsets the cost of the ducts required with the air system. In addition, the bottled system requires additional piping.

However, the difference in capital costs is not significant. The choice is between the added safety of the air system and the improved dryness and cleanliness of the bottled system. The air system is recommended.

For "A" Chamber

	Air + Bottled O_2 (62 1/2%) (37 1/2%)	Bottled N_2 + Bottled O_2 (50%) (50%)
Total Repressurizing Gas (1)	10,000 lb.	10,000 lb.
Bottled O_2 (2)	3,750 lb.	5,000 lb.
Bottled N_2 (2)	———	5,000 lb.
Number Of Bottles (3)	16	40
Cost Of Bottles	\$20,000	\$50,000
Cost Of Ducts & Filters	35,000	———
Cost Of Piping, etc.	80,000	100,000
Total Cost	\$135,000	\$150,000

(1) Based on final temperature of 176°F and final pressure of 5 psia, final temperature may vary between the two systems but its effect can be ignored for this analysis.

(2) Ignoring the amount of backup gas required to get flow rates required.

(3) 12" OD, 40 ft long, bottles @ 2400 psia - approximate 300 lbs gas/bottle and allowing for backup gas and for division into 4 cascades.

12.3 Freeze out - The cryopanels will freeze out a part of the repressurizing gas as it enters the chamber. The total amount so affected and its later sublimation will depend on the transient temperature balance at the surfaces of the cryopanels. An analysis of this should be considered in final design along with the temperature analysis of the chamber. This freeze out effect has been ignored in the calculation reported here.

12.4 Gaseous vs Liquid Storage - Gaseous and liquid storage of the bottled oxygen were compared. Because of the need for almost instantaneous vaporization of the liquid and because the fast generation of required heat quantities is costly, only gaseous storage should be considered.

12.5 Storage Pressure - The selection of the air system was based on the maximum commercial storage pressure for gaseous O_2, 2400 psi .

Storage systems at lower pressures were also considered. At 1200 psi the number of bottles required is twice that needed at 2400 psi and although the cost of each bottle is less, the cost of the complete system is higher. At 300 psi the use of bottles is impractical. A spherical vessel storing 3750 lb of oxygen at 300 psi has a diameter of 17.5 ft and would cost over 50 percent more than the high-pressure bottles. A 2400 psi storage is therefore, recommended for the oxygen storage.

For air, a 300 psi system could be built which would permit pre-drying. This system would require a sphere about 21 feet in diameter plus air compressors and dryers. The cost of such a system is somewhat greater than an atmospheric system and is less reliable. Therefore, the atmospheric system is recommended.

12.6 Injection Areas - The gas can be injected at any convenient point in the vessel provided that pressure and shock waves can be controlled. Three basic schemes have been considered:

1. Injection in the lower part of the vessel using a space below the lunar plane as a plenum.
2. Injection in the upper part of the vessel and adding plenum space as necessary.
3. Injection at several points and using an extensive internal distribution system to eliminate the need for a plenum space.

For Chamber A, the first scheme would utilize space that would exist within the vessel for other reasons. Since the duct approaches to the vessel are to through underground tunnels, a bottom injection is economical.

The main disadvantage of the bottom system is that some portion of the work floor must act as a louvred diffuser to distribute the gas from the plenum to the main chamber area. This increases the hazard to an astronaut who is on this floor area during repressurization. Another disadvantage is that the gas rising in a cylindrical envelope may strike the chamber roof and be reflected down, causing excessive noise levels.

Top injection does not impinge the blast directly upon an astranaut on the lunar plane and does not require any diffusers in the main floor. The top injection has the disadvantages of possibly impinging on the command capsule and on an astronaut in the process of entering or leaving the capsule or climbing up or down the outside of the vehicle. The top injection system also would require that additional height or special plenum space be built onto the chamber.

The internal distribution system has the advantage of delivering the repressurizing gas simultaneously into many points of the chamber. However, this system would be costly and might cause harmful impacts.

Bottom injection is recommended for both Chamber "A" and Chamber "B".

12.7 <u>Control of Impact Pressures and Sound Levels</u> - There are very little data available for designing an internal plenum and baffle system to control pressure and sound levels during repressurization. Consultation with aero dynamicists and others experienced in the field of high velocities and low pressures indicates that such a design is feasible. After examining several methods of valving and baffling, it was determined that the bottom plenum area offers adequate space for one of several different design approaches.

Basic recommendations are as follows:

a. Injection should be multipoint for better distribution around the periphery. (This also improves dependability).

b. The repressurizing gas should immediately impinge on a baffle or set of baffles designed to stagnate the gas.

c. The plenum area and succeeding baffles should be used to expand and distribute the gas at low velocities to the diffusers.

d. The main diffusers should deliver the gas to the main chamber volume and auxilary diffusers should deliver lesser amounts to the areas behind the cryopanels and other areas not easily filled from the main area.

e. The main diffusers should serve as a part of the operating floor. They must a) be optically dense, b) be cryocooled to complete the heat sink enclosure, and c) offer a suitable walking surface.

f. The plenum area should be comprised of the space below the lunar plane which is not otherwise encumbered with the turntable supports and mechanism and the various piping, electrical, and instrumentation connections to the plane.

g. The plenum enclosure and diffusers should be designed to withstand the stagnation pressures developed in the plenum area during repressurization, including shocks, standing waves, etc.

h. Other chamber components, particularly the cryopanels, should be designed to withstand the pressures, resonant frequencies, and other conditions to be met during the cycle.

12.8 Performance - Along the centerline of each discharge nozzle, the gas velocity will persist at supersonic velocity and impact pressure will peak at about 14.7 psia when this stream impinges on a baffle or other surface. The impact pressure falls rapidly as a function of distance from stream centerline. A standing tail shock will precede impact, and acoustic waves will reflect from all surfaces.

Assuming about 550 ft^2 of annular area around the revolving floor, the initial pressure under the floor will rise quickly to about 0.06 psia, and impact pressures along the projection centerline of the annulus would be not over this figure. Again, weak standing shock-type pressure rises will precede any surface impacted, and acoustic wave reverberation will occur by reflection from impacted surfaces.

Impact pressures should be less than 15 psf throughout the cycle but shock wave formation in the chamber should disappear very early. High acoustical levels will probably persist in the chamber throughout the cycle. Some convergence of reflected acoustic wave energy can be expected for a few seconds as the result of impact on the chamber top. Although the reflections may develop severe levels near the top of the vehicle, nothing injurious is expected. Since the gas stream will probably form a toroidal vortex in the chamber, personnel along catwalks would be subject to some buffeting.

The atmospheric air entering the chamber will be expanded and accelerated as it passes through the nozzles. The temperature of the flowing stream will, therefore, be quite low and may cause external icing on the nozzles if they are not insulated.

The entire repressurizing scheme needs to be verified by use of models and wind tunnel tests. Finally the entire repressurizing cycle must be checked out full scale with pressure instruments and microphones in the chamber to assure safe operation.

12.9 Control Of Temperature - The temperature of the gas in the chamber during and immediately after repressurization will depend on the following:

a. The cryopanel temperature at the time repressurization begins.

b. The rate of removal of the nitrogen and helium from the cryopanels.

c. The temperature of the lunar plane at the time repressurization begins.

d. The heating of the air as the pressure rises.

e. The cooling of the bottled oxygen as it enters the chamber.

f. Additional heating and/or cooling that may be employed to control temperatures.

g. Local heating effects due to turbulance and impact during rapid repressurization.

h. The heat conduction within the chamber as the pressure rises.

The interaction of the above factors and the transient nature of the phenomena preclude a detailed analysis at this time. Preliminary calculations, however, indicate that the temperatures will be tolerable, and that the general scheme is feasible.

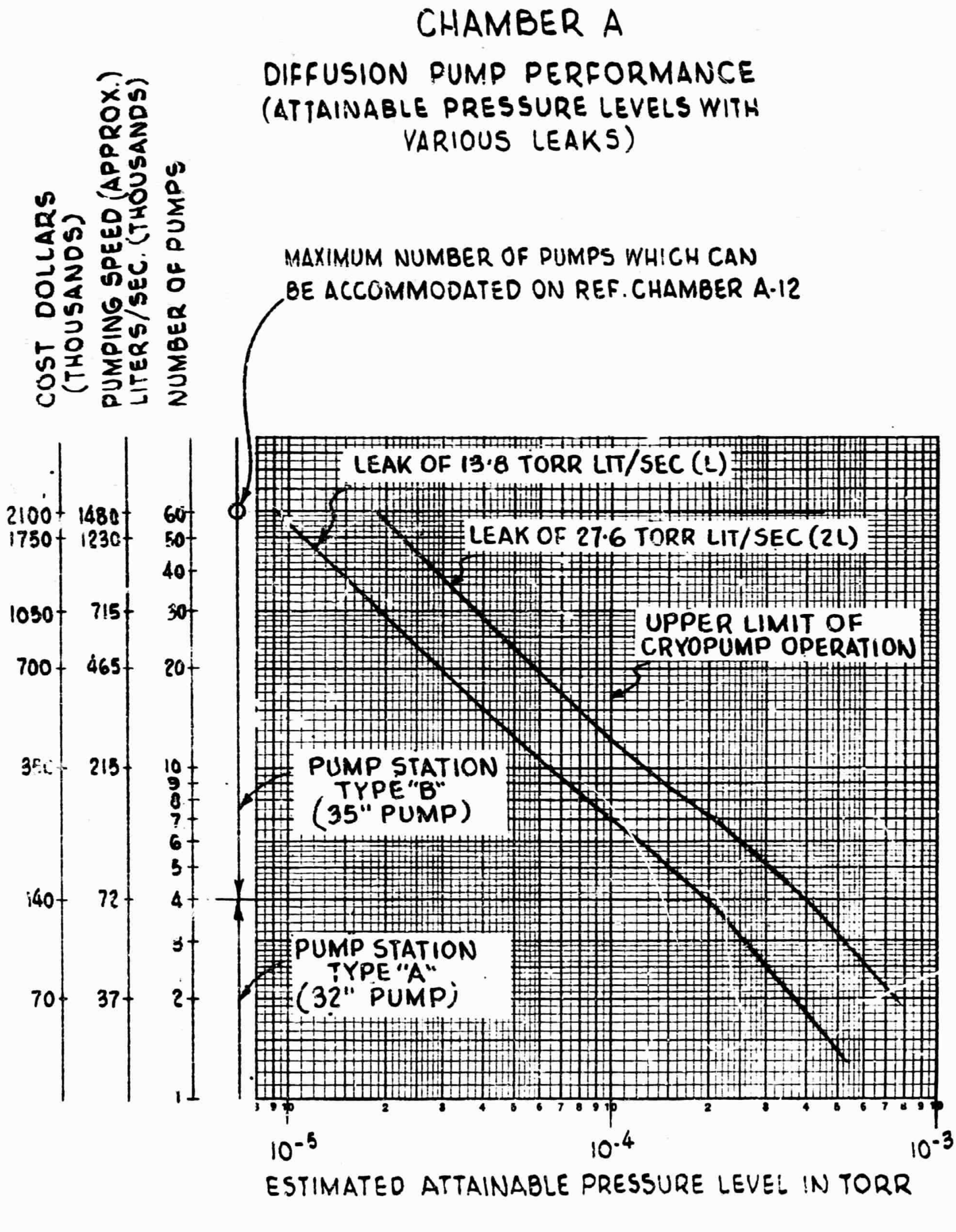
CHAMBER A
DIFFUSION PUMP PERFORMANCE
(ATTAINABLE PRESSURE LEVELS WITH VARIOUS LEAKS)
COST DOLLARS (THOUSANDS)
PUMPING SPEED (APPROX.) LITERS/SEC. (THOUSANDS)
NUMBER OF PUMPS
MAXIMUM NUMBER OF PUMPS WHICH CAN BE ACCOMMODATED ON REF. CHAMBER A-12
LEAK OF 13·8 TORR LIT/SEC (L)
LEAK OF 27·6 TORR LIT/SEC (2L)
UPPER LIMIT OF CRYOPUMP OPERATION
PUMP STATION TYPE "B" (35" PUMP)
PUMP STATION TYPE "A" (32" PUMP)
2100
1750
1050
700
140
70
1480
1230
715
465
215
72
37
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
10^{-5}
10^{-4}
10^{-3}
ESTIMATED ATTAINABLE PRESSURE LEVEL IN TORR

FIG. IV-1

CHAMBER A

CRYOPUMP PERFORMANCE
(ATTAINABLE PRESSURE LEVELS WITH VARIOUS LEAKS)

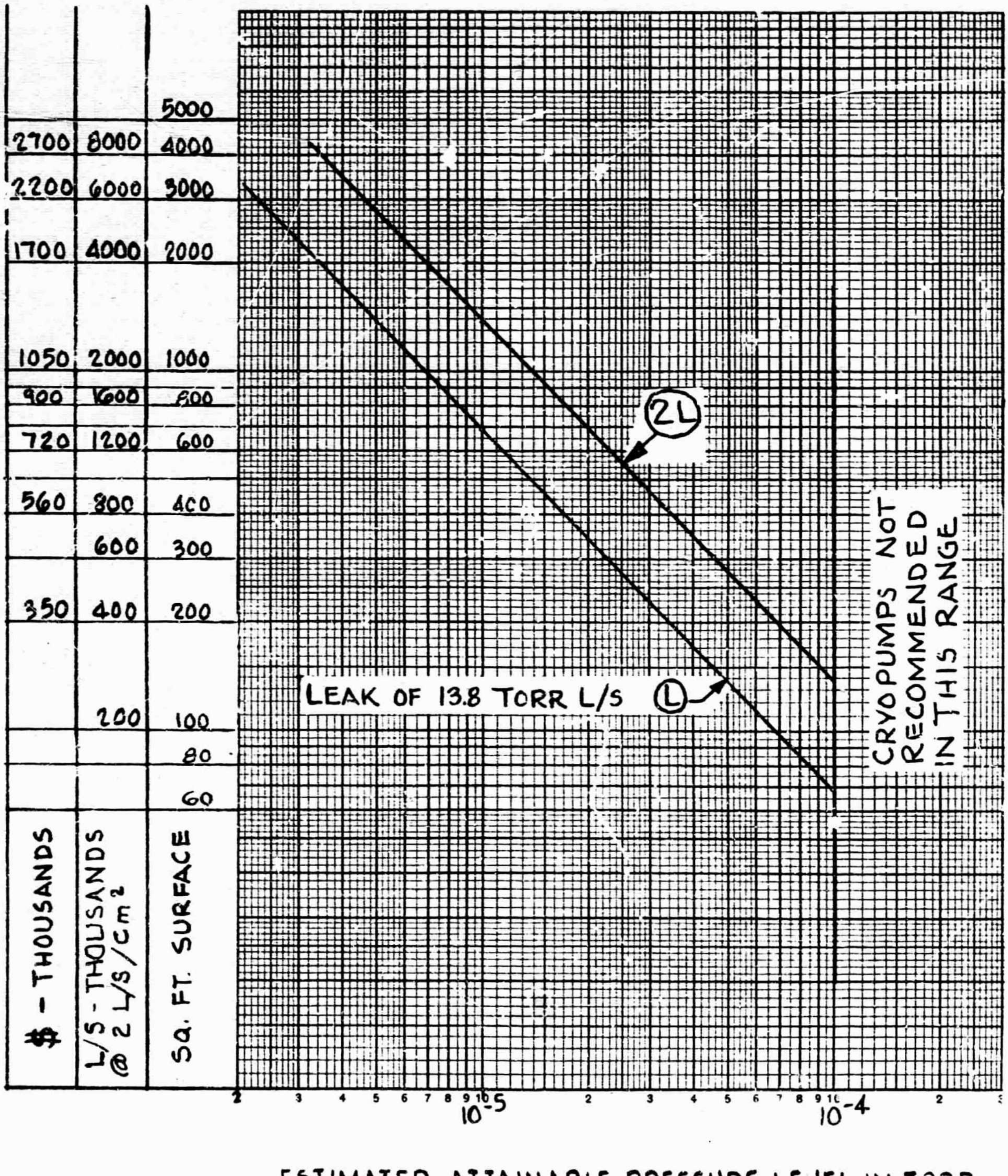

FIG. IV- 2

CHAMBER B

TYPES AND SIZES OF PUMPING SYSTEMS
V.
ATTAINABLE PRESSURE LEVELS AT VARIOUS "LEAK" RATES

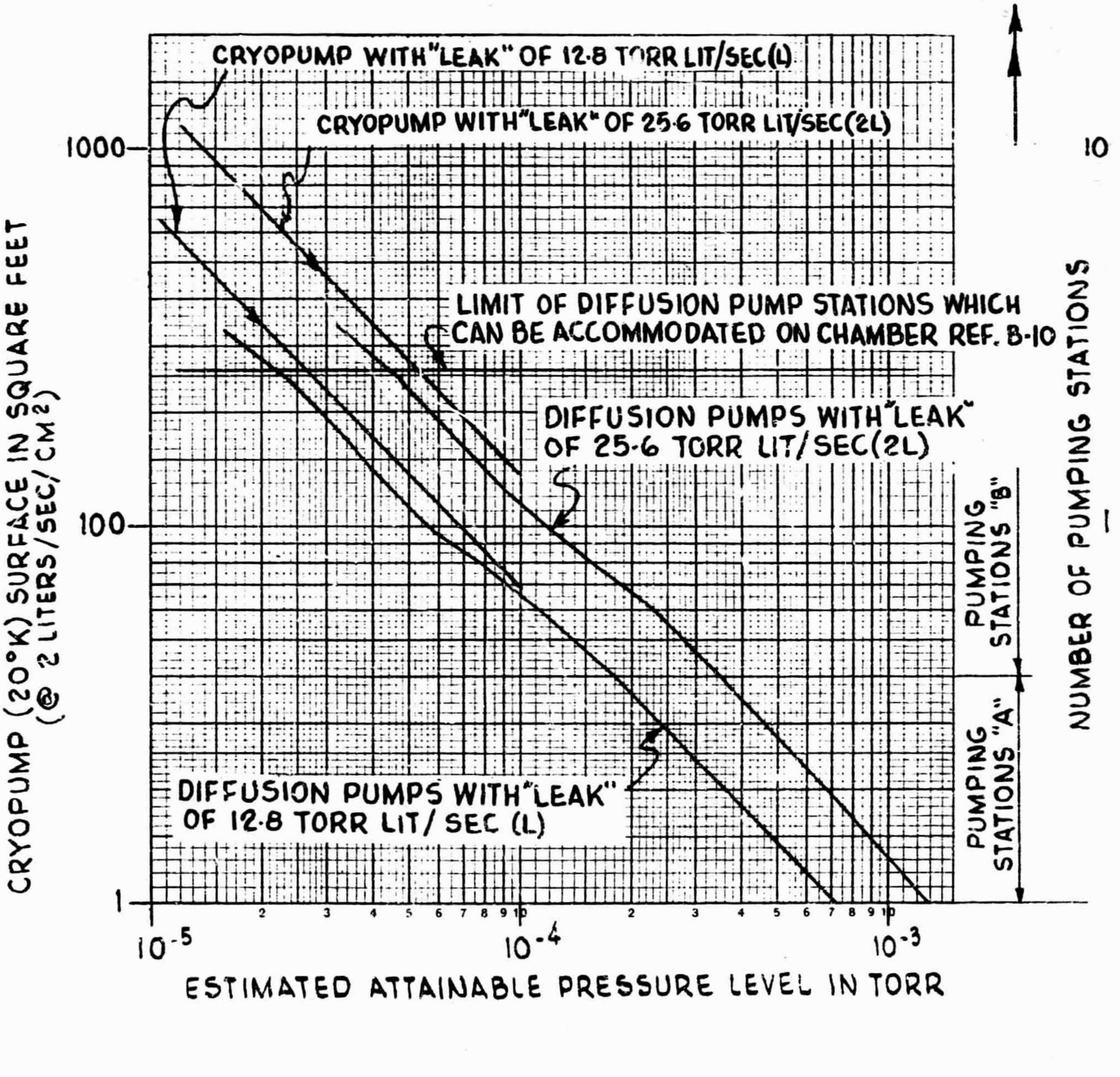

FIG. IV-3

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SECTION V
VEHICLE MOUNTS AND HANDLING

1.0 Rotation - A requirement in Chambers A and B was to rotate the vehicle about its longitudinal centerline while perpendicular to a supporting plane in the chamber. A simulated lunar plane coincident with the vehicle supporting plane in the chamber was also necessary to provide an area for astronaut training, tests simulating lunar landings, and the associated heat balance effects. These requirements, imposed on a chamber whose most economical and practical configuration was circular, dictated a rotary table. Vehicle vibration was not compatible with any rotary table investigated.

Consideration was given to two drives. One, a steel belt, (Fig. V-1) offered high efficiency, no slippage, less bearings, and no additional transmission means.The second design was a gear drive also shown on the figure which offered high efficiency, good loading characteristics, state-of-the-art tooling, and production techniques, minimum side thrust, low backlash, minimum space requirements, and low maintenance. All these advantages combined to define this drive as the one with the most desired characteristics.

Considerations were given to hydraulic and electric motors as prime movers for the rotary table. In the latter type, both internal and external mountings were investigated. Hydraulic motor drives were eliminated due to the possibility of hydraulic fluid leakage within the chamber. Electric motor manufactures indicated that a motor compatible with the chamber environment was on the frontier of current technology for a vacuum of 10^{-8} torr but that motors could be built for operation at 10^{-5} torr. Methods of canning and sealing an electric motor within a friendly environment were considered in case such an alternate was necessary. In this case a rotary seal of the two-step magnetic type could be used with dry lubrication. Mounting of the prime mover and associated gear drive external to the chamber was relegated to a secondary consideration, because of shaft sealing problems created by the chamber wall penetration and bearings on long shafts. These difficulties are not encountered in an internally mounted prime mover and associated gear drive. A further alternate drive considered were sealed linear oscillating devices. This latter type drive could be completely sealed by using a flexible bellows and thereby avoid a rotary seal.

Bearings cannot be lubricated in the conventional manner for vacuum service because of the high vapor pressure of lubricants. Molybdenum disulphide however, would be suitable to pressures of 10^{-8} torr but it is expensive.

Other lubricants were investigated such as DC 704 and graphite. At the design pressure of 10^{-5} torr, the silicone oils are most suitable.

A fixed mount was briefly investigated but eliminated because of the extreme complexity of rotation of the solar beam, either actual or programmed. Problems involved in rotating an externally mounted solar beam are the large number of optical ports required, interference with external pumps, piping, access ports, etc. Internally, a rotating solar beam would require lining the chamber with lamps. Loss of cryogenic cooling area and the large amount of piping and wiring required made this concept unacceptable.

The rotary mount in Chamber B was replaced by the Revised Guidelines, with a fixed mount capable of being upgraded to a rotary one. A fixed vehicle mount concept was developed to accommodate the latter addition of the necessary rotating mechanisms. Spacers would initially be installed.

2.0 Pitch and Roll - Two "A" frames supporting a roll mount (Fig. V-2) make it possible to remove the test vehicle remotely from the mount and place it on a vibrating source. Difficulties in the design of this mount would be experienced in sealing the drive and bearings at 10^{-8} torr. Using this mount, the solar simulator could be placed anywhere within the chamber if its center intersected the centerline of the roll axis. The two axes of rotation provided by this method of module support make it possible to use a stationary simulator and mount the "A" frame on a stationary floor.

The vehicle module could also be supported in trunnions to permit rolling (Fig. V-3). The trunnions would in turn be placed on a rotary mount to provide the two-axes motion desired. This design concept does not provide the freedom of vibrating the test module that the previous design afforded. Greater utilization of the solar simulator can be obtained with this type of support, due to lack of structural members around the module.

3.0 Vehicle and/or Module Handling

3.1 Handling External to Chambers - Vehicles and/or modules will be brought into the chamber complex via truck trailers. It is assumed that dollies associated with the vehicles and designed by others, will be attached to the vehicle and available for use in intra-plant movement. In the early phases of the study, before this assumption was made, several concept designs of universal dollies for the facility were developed (Fig. V-4.) The vehicles and/or modules will be removed from the trucks using the building bridge crane.

3.2 Handling Vehicles and/or Modules into Chamber A - Three methods were considered for loading vehicles and/or modules into Chamber A. They were a) all top loading (Fig. V-5), b) side loading with limited top loading (Fig. V-6), and c) all side loading (Fig. V-7). The first method, all top loading, was discarded because building heights became excessive and presented formidable structural design problems. Further consideration of the second method, showed that the advantages of limited top loading could be offset by the disadvantages of removing the top which would require flexible electrical and cryogenic disconnects to the solar simulator and liquid nitrogen panels. Further design layouts indicated that it could be possible within the side loading concept to remove the Apollo command capsule from the service module and lower it to the floor for removal from the chamber without removing the service module. This capability eliminates the chief advantage of limited top loading, therefore side loading is recommended.

There were three possible alternates for handling within Chamber A. One was externally mounted hoists with manually removable covers on ports in the head so that the hoist hooks could be lowered into the chamber. The second was internally mounted hoists, but these would require use of flat steel belts in lieu of stranded cable as the latter presented serious out-gassing problems. The third was specialized handling equipment mounted on special dollies which could also be used to move the modules into the chamber. In the interest of economy and flexibility, the latter two means were discarded and externally mounted hoists are recommended.

3.3 Handling Modules into Chambers B and C - Since the chamber design became a top opening vessel concept, top loading using the building bridge crane was the most expedient method and it is recommended.

4.0 Instrumentation, Communication, and Power Connections to Vehicles and/or Modules in Chambers A and B - Hard line electrical connections are required between the vehicle and/or modules under test and the recording or indicating instruments at the main control panels for Chambers A and B. In Chamber A, the problem is a more difficult one since the connecting lines must go through the rotary mount into the vehicle and/or module in a manner to allow the table to rotate $\pm$ 180° (0° to 360°). The Chamber A rotary table design could provide up to 24 inch diametrical clearance for the passage of these wires through the center. It is probable that the cable bundle will require heating to maintain its flexibility at 100°K.

In Chamber B, since the mount is fixed at present, providing an adequate means of electrical connections is not a problem.

5.0 **Heat Sink and Lunar Plane Required in Chambers A and B** - Temperature extremes from 77°K to 410°K in the initial Guidelines impose material restrictions on the lunar plane. With the need for a solid floor plate to support liquid nitrogen tubing and alternate heater wires for the simulated lunar plane, temperature differentials in the rotary table structural members will cause significant differential expansion. This means that the floor plate design must provide a means of movement between themselves and the supporting structure. This problem has not been completely solved but various alternatives are available and during the design phase should be considered.

6.0 Recommendations

6.1 Chamber A and B Rotary Mount

a. A canned electric motor as the prime mover driving the table through a gear driven power transmission unit that will provide the proper rotational speed and control.

b. A turntable constructed of aluminum welded subassemblies and containing floor plates that will provide a maximum heat transfer for lunar surface simulation and sufficient load carrying capacity to support the required personnel and vehicle and/or module under test.

c. The main turntable frame to be of eight legs spaced 45° from each other. At a radius of 18-1/2 ft from the center, outrigger ball bearing roller supports to provide for increased load carrying capacity and stability.

d. Space for ample clearance through the center of the rotary mount for all power and instrumentation leads.

e. Vibration of the vehicle and/or module under test in Chambers A and B should not be accomplished on the rotary mount. It will be necessary to isolate the test article from the rotary mount when a vibration test is to be performed.

6.2 Chamber C Roll and Pitch Mount

a. Use of two "A" frames supporting a gimbal mounted frame to provide the roll and pitch motions.

6.3 Handling Vehicles and/or Modules into Chamber A -

a. Side loading into the chamber is recommended.

b. Modules should be brought through the door on a dolly designed to be compatible with the chamber.

c. The module should be raised from the dolly inside the chamber with four externally mounted hoists penetrating the chamber through manually opened pressure seals. After raising the module the dolly should be removed.

d. The second module should be brought into the chamber in the same manner as the first. The first module is lowered onto the second module and the two mated. Lifting the two modules after joining allows the dolly to be removed.

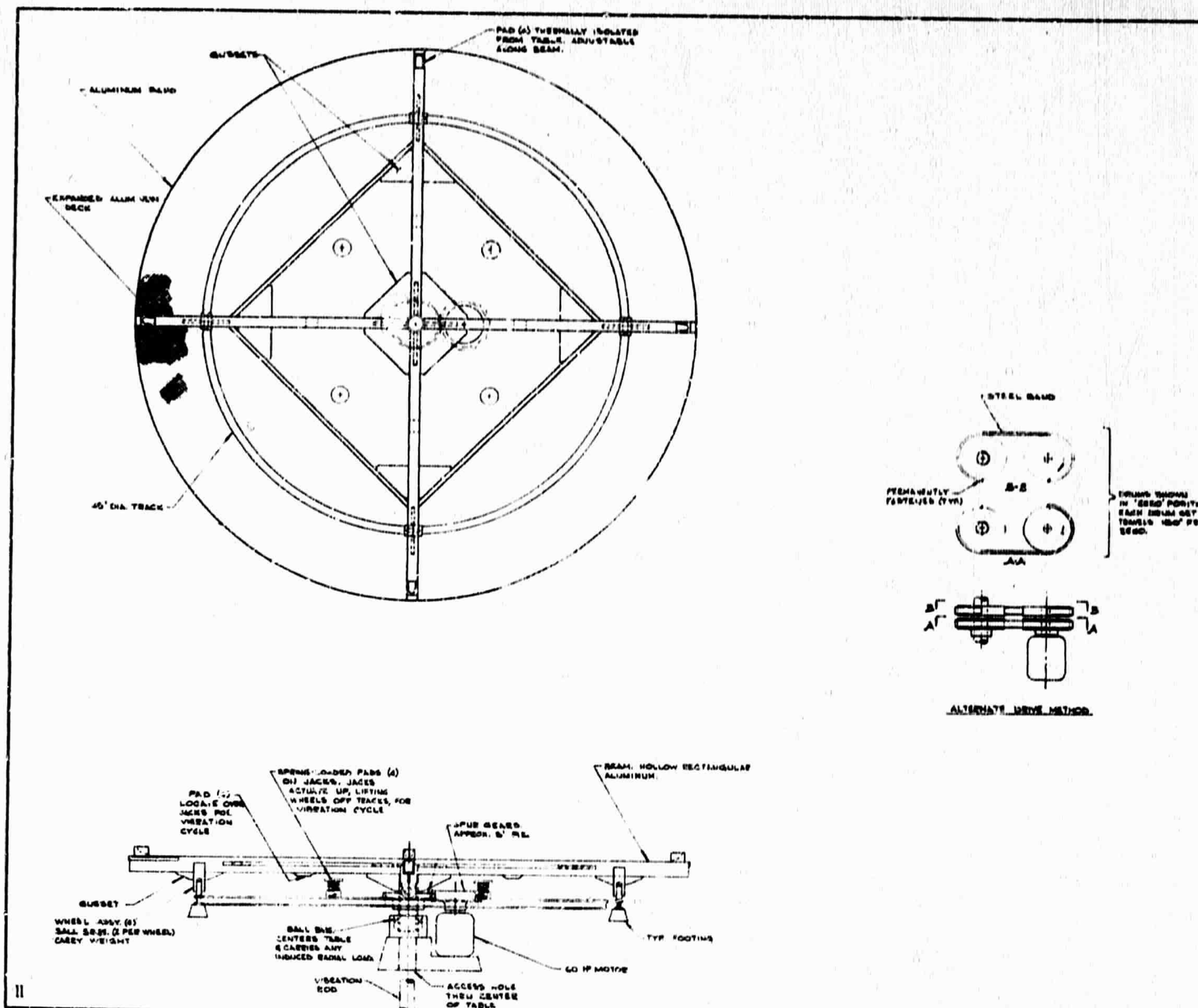
e. Unloading the modules from the chamber should be the reverse sequence of the loading operation.

f. For vehicles with modules longer than the Apollo vehicle, special loading fixtures will be required such as a dolly with a strongback capable of lifting one end.

g. Using diagonally opposite crane hooks and by paying out cable on one while raising the other will allow the operators to remove a command module without emptying the entire chamber. This operation will be a delicate one because of close clearances, but will provide a means of accomplishing this task if desired.

6.4 Handling Modules into Chambers B and C -

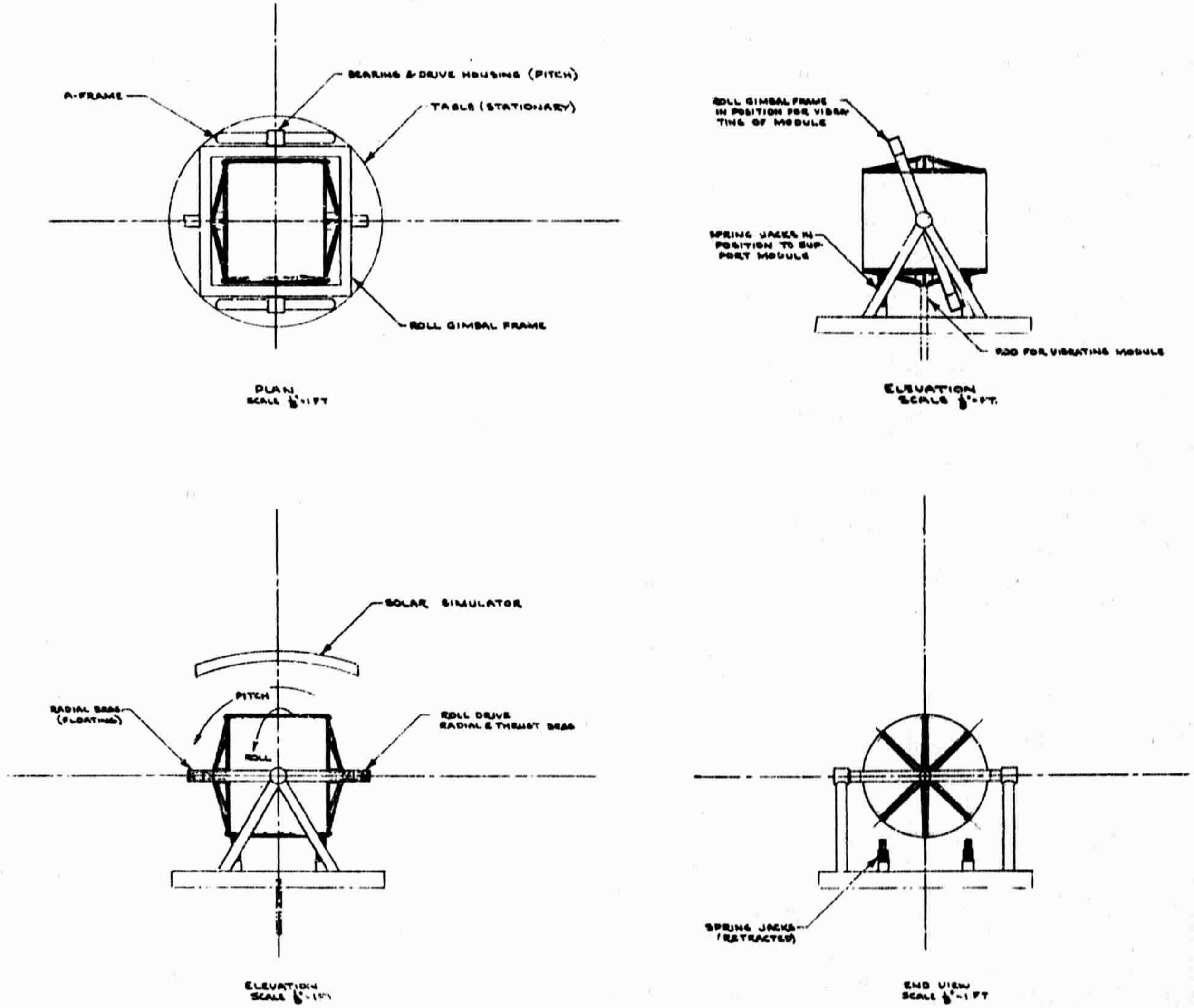
a. The recommended procedure is to use the building bridge crane to remove the top head and also to load modules into or remove them from the chambers.



APPROX. WGT. = 40,000# FOR TURNTABLE IN CHAMBER "A"

APPROX. WGT. = 20,000# FOR TURNTABLE IN CHAMBER "B"

FMC CORPORATION SAN JOSE, CALIF.	
BECHTEL CORPORATION SAN FRANCISCO	
NASA MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY	
TURNTABLE	
485	FIG V-1



CALCULATIONS

ASSUME EACH SPIDER WEIGHS 10000# INCLUDING STRUCTURE, BRGS, DRIVES & OTHER HARDWARE.

MODULE + 2 SPIDERS = 80,000#

THRUST LOAD (TOTAL)

ROLL GIMBAL FRAME MUST SUPPORT

FULLY RESTRAINED SIMPLE BEAM

BEAM LARGER THAN NECESSARY IN BENDING BUT DEFLECTION PROBABLY WOULD CONTROL DESIGN.

HP (ROLL)

ROTATIONAL VEL $1\frac{1}{2}$ RPM

ASSUME 12' DIA BRG.

= .6 HP

PITCH

APPROX WT 55,000#

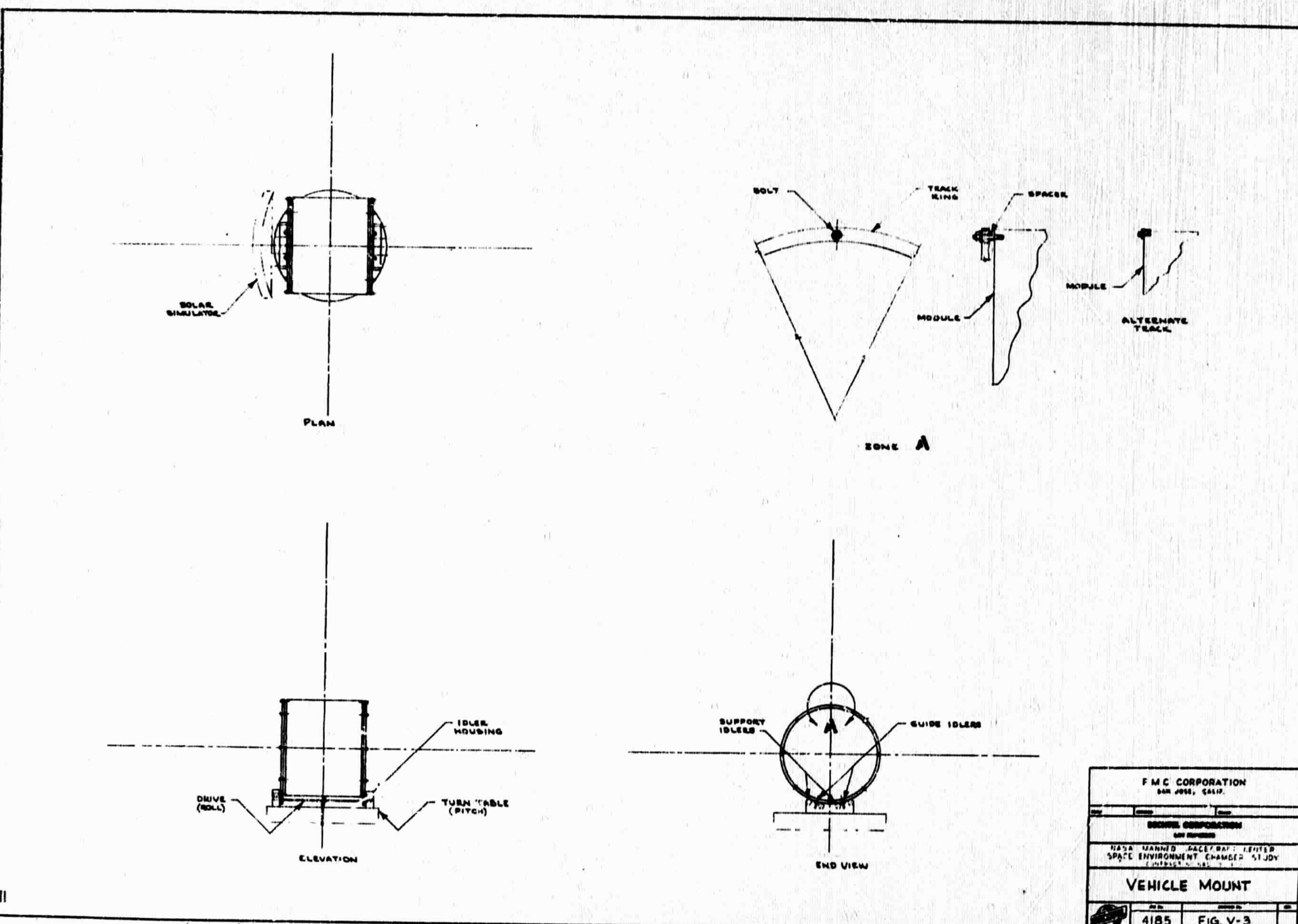
F M C CORPORATION
SAN JOSE, CALIF.

BECHTEL CORPORATION
SAN FRANCISCO

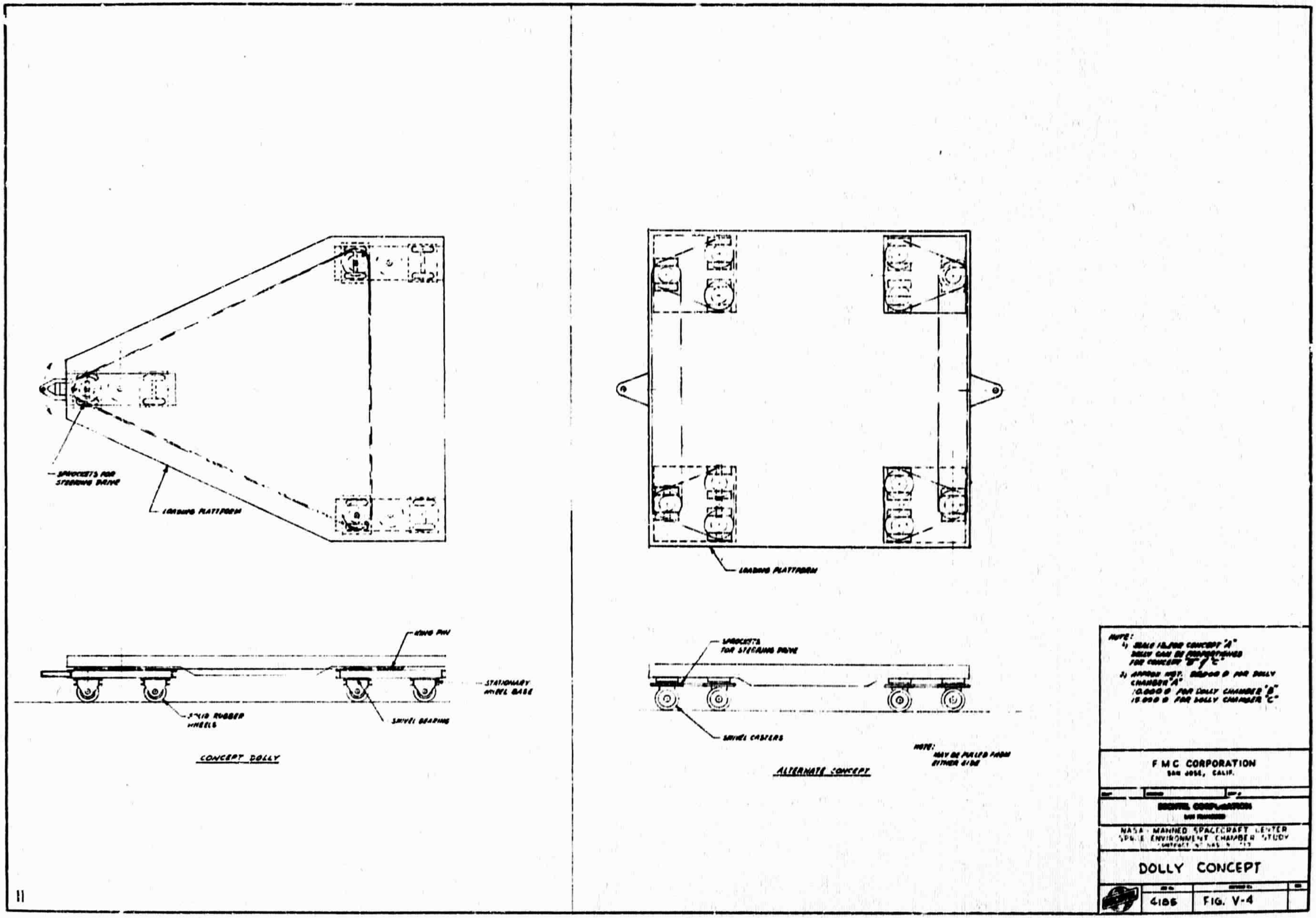
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

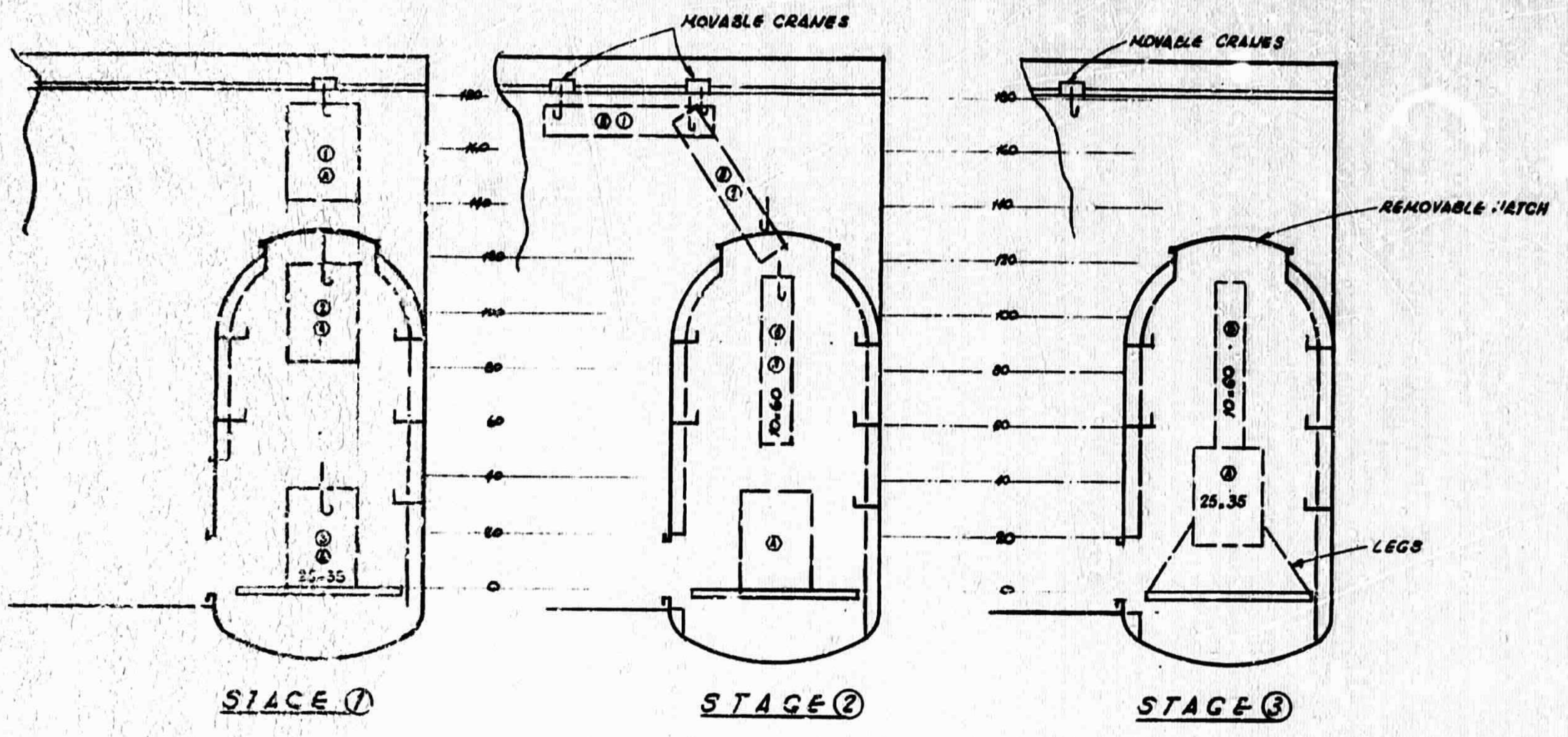
VEHICLE MOUNT

4185 | FIG. V-2

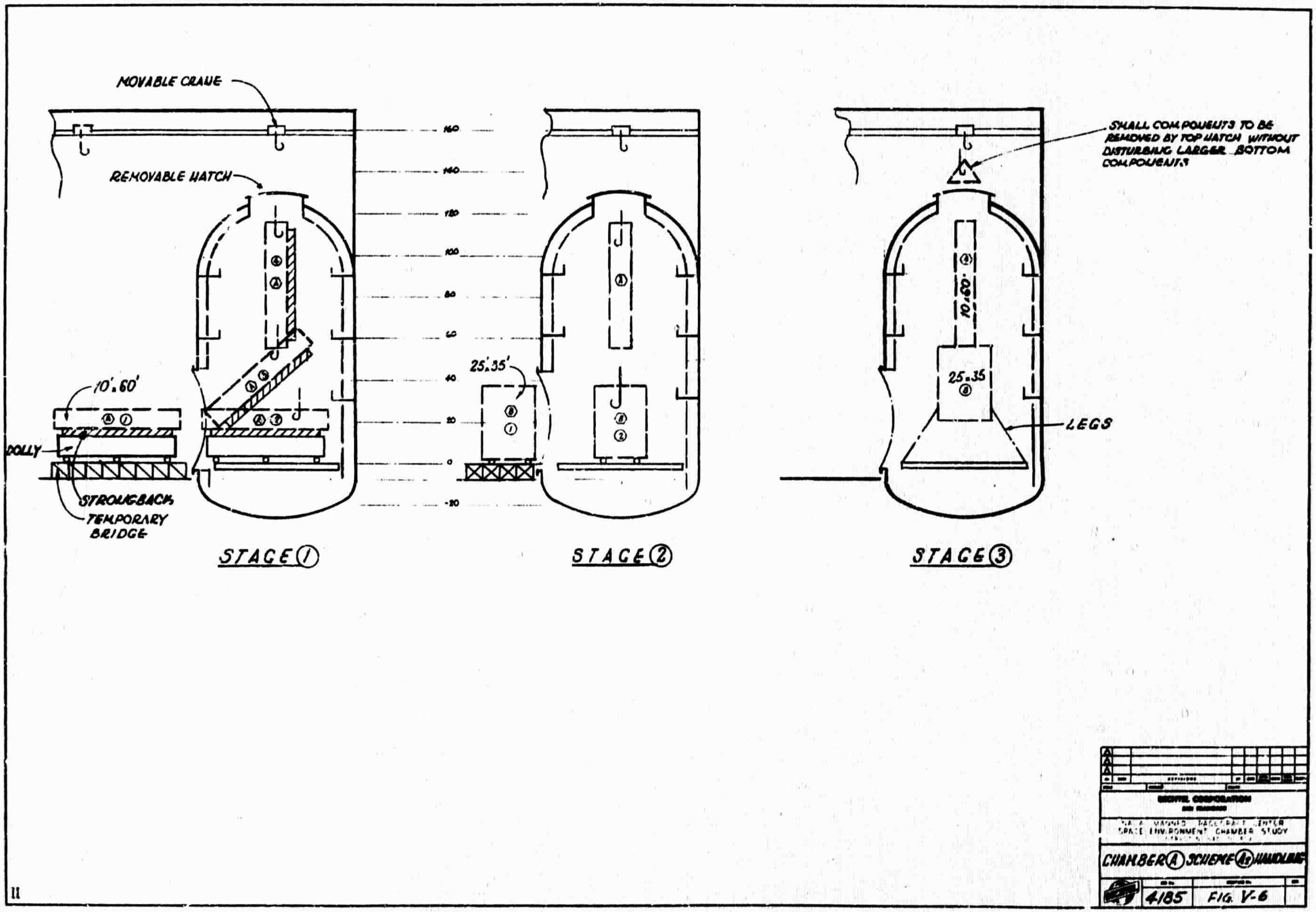

BOLT
TRACK RING
SPACER
MODULE
MODULE
ALTERNATE TRACK
ZONE A
PLAN
SOLAR SIMULATOR
IDLER HOUSING
DRIVE (ROLL)
TURN TABLE (PITCH)
ELEVATION
SUPPORT IDLERS
GUIDE IDLERS
END VIEW
F M C CORPORATION
SAN JOSE, CALIF.
BECHTEL CORPORATION
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
VEHICLE MOUNT
4185
FIG. V-3

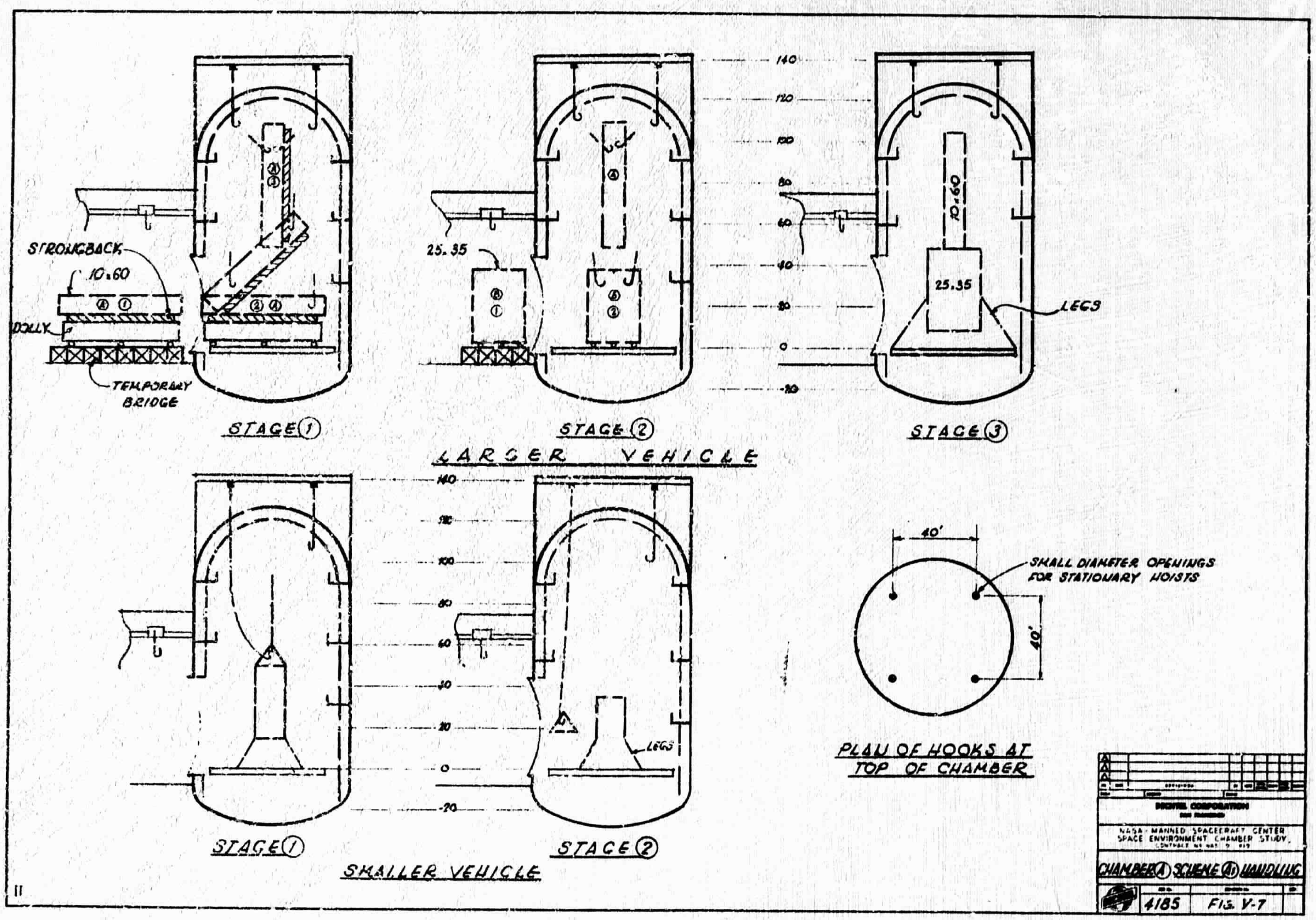
II


SPROCKETS FOR STEERING DRIVE
LOADING PLATFORM
KING PIN
STATIONARY WHEEL BASE
SOLID RUBBER WHEELS
SWIVEL BEARING
CONCEPT DOLLY
LOADING PLATFORM
SPROCKETS FOR STEERING DRIVE
SWIVEL CASTERS
NOTE: MAY BE PULLED FROM EITHER SIDE
ALTERNATE CONCEPT
NOTE:
10,000 # FOR DOLLY CHAMBER "B"
15,000 # FOR DOLLY CHAMBER "C"
F M C CORPORATION
SAN JOSE, CALIF.
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
DOLLY CONCEPT
4186
FIG. V-4



BECHTEL CORPORATION
SAN FRANCISCO
NASA · MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CHAMBER (A) SCHEME (2C) HANDLING
4185
FIG. V-5


MOVABLE CRANE
REMOVABLE HATCH
10'.60'
DOLLY
STRONGBACK
TEMPORARY BRIDGE
160
140
120
100
80
60
40
20
0
-20
25'.35'
10'.60'
25.35
LEGS
SMALL COMPONENTS TO BE REMOVED BY TOP HATCH WITHOUT DISTURBING LARGER BOTTOM COMPONENTS
STAGE ①
STAGE ②
STAGE ③
BECHTEL CORPORATION
SAN FRANCISCO
SPACE ENVIRONMENT CHAMBER STUDY
CHAMBER (A) SCHEME (A2) HANDLING
4185
FIG. V-6


STRONGBACK
10.60
DOLLY
TEMPORARY BRIDGE
STAGE (1)
25.35
STAGE (2)
140
120
100
80
60
40
20
0
-20
10.60
25.35
LEGS
STAGE (3)
LARGER VEHICLE
LEGS
STAGE (1)
STAGE (2)
SMALLER VEHICLE
40'
SMALL DIAMETER OPENINGS FOR STATIONARY HOISTS
PLAN OF HOOKS AT TOP OF CHAMBER
BECHTEL CORPORATION
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CHAMBER (A) SCHEME (A1) HANDLING
4185
FIG. V-7

11

SECTION VI
CRYO - ARRAYS

1.0 Heat Sinks

1.1 Operating Temperature - To a vehicle in outer space, the surroundings appear to be an enclosing black body at about 3°K in which exist several sources of radiation. In the vicinity of the earth, the sun, earth and moon are the sources; radiation from other celestial bodies accounts for the non-zero space "temperature".

If life is to be supported within the vehicle, it will operate at about 300°K surface temperature. The equation relating this temperature to its environmental conditions has the following form:

$$\sigma A(T_v^4 \epsilon_v - T_s^4 \alpha_v) - \sum_i \phi_i A_i \alpha_i g_i = 0$$

where
- σ = the Stefan - Boltzmann constant
- A = vehicle surface area
- T_v = vehicle surface temperature
- T_s = temperature of black space
- ϵ_v = vehicle total hemispherical emissivity
- α_v = vehicle total absorptivity for 3°K black body radiation
- ϕ_i = energy flux at the vehicle from source " i "
- A_i = projected area of vehicle perpendicular to flux from source " i "
- α_i = absorptivity of vehicle for radiation from source " i "
- g_i = geometric factor accounting for the possible variation of α_i with angle of incidence.

If it is assumed that the vehicle is grey,

$$\epsilon_v = \alpha_v$$

Then

$$\sigma A \epsilon_v (T_v^4 - T_s^4) = \sum_i \phi_i A_i \alpha_i g_i$$

Because this equation contains T_v and T_s as the difference of fourth powers, it is relatively insensitive to low values of T_s for expected values of T_v. For a vehicle temperature of 300°K, the error resulting if T_s is 100°K rather than 3°K is 1 1/4%.

Consequently, in space chamber experiments, if black surroundings at temperatures attainable with nitrogen refrigeration are employed, adequate simulation is achieved. If the cryopanels are not black ϵ_v must be replaced by:

$$\frac{1}{\frac{1}{\epsilon_v} + \frac{1}{\epsilon_c} - 1}$$

where ϵ_c is the emissivity of the cryopanels.

Since the value of ϵ_c, after frost deposition is about 0.8, the corrections involved are small.

Therefore, liquid nitrogen cryopanels at less than 100°K provide adequate thermal simulation of actual space conditions.

1.2 Material Selection - The use of materials at cryogenic temperatures requires careful consideration. Although the ultimate strength of materials increases as their temperature is decreased, their ductility, malleability, and notch sensitivity usually decrease with temperature. As a result, many materials are not satisfactory for cryogenic equipment because of the danger of brittle fracture.

Stainless steel, copper and aluminum are suitable for use at cryogenic temperatures. All these materials can be fabricated into complex shapes by working and welding or brazing techniques. Stainless steel has a very low thermal conductivity and is relatively expensive. Copper has a high conductivity and is easily worked but is much heavier than aluminum. Aluminum has a high conductivity, is light weight and is easily worked. Although it is somewhat difficult to fabricate, techniques have been developed in the last few years which consistently result in high quality products. Considering heat transmission, ease of fabrication, cryogenic service and strength to density ratio, aluminum is the most suitable material. The aluminum should be anodized on the surface exposed to the vehicle to insure a high thermal emissivity.

1.3 Design - In the design of the heat sink cryopanels, there are two criteria for effective simulation:

(a) The cryoarray should completely surround the vehicle.

(b) The surface temperature of the cryoarray should not be greater than about 100°K at any point.

The first of these criteria implies that ports which admit solar radiation, etc., should be as small as possible and that doors for air locks should be light trapped or carry their own cryopanels.

Figs. VI-1, VI-2 and VI-3 show several heat sink and cryopump arrangements. The heat sink must not seriously hinder the flow of gas to the vacuum pumping ports and must not permit direct radiation from the chamber walls to reach the vehicle. These conditions are met by arranging the panels in a staggered pattern. The preferred arrangement, shown on Fig. VI-3, consists of 3 ft wide panels with a 2 inch overlap and 2 inch right angle extensions which prevent the radiation of the chamber walls from directly hitting the helium cryopumping surfaces. The second criteria is met by selecting the tube spacing and/or the web thickness to minimize the temperature variation between tubes.

In Figs. VI-4 and VI-5, several panel configurations are shown which meet these criteria. The principal differences in these concepts are summarized as:

a. Safety - Types I, II, IV, V and VII, offer additional material between the vehicle and the liquid nitrogen

b. Control - Type V might develop minor warm spots.

c. Cost - Type VI appears somewhat less costly than the other designs.

At the present time, Types I and II appear to best satisfy all the requirements. However, in view of the rapid advances being made in fabrication techniques, a different type may better satisfy the requirements by the time the detailed design has been completed.

1.4 Control Zones - By dividing the cryopanels into separate externally controlled zones, several objectives can be accomplished. The variation in incident thermal flux can be accommodated by individually adjusting the flow rate to each zone. If a failure occurs in a panel, it can be isolated, thus permitting the test to continue under some conditions. The quantity of cryogenic fluid which could spill into the chamber if a major panel break occured, is reduced in direct proportion to the number of zones. This reduces the hazard to man and equipment within the chamber.

The manifolding for the zones will be done outside the chamber and for the panels, inside the chamber. Control valves will only be used for the external zone manifolding to minimize the valving within the chamber.

2.0 Lunar Plane

2.1 General - An evaluation was undertaken to select the material of construction and the heating and cooling systems which will meet the lunar plane requirements most effectively and economically. Based on this evaluation, aluminum appears to be the preferred material. The plane should be heated by electric resistance heaters and cooled by liquid nitrogen circulating in aluminum pipes welded to the plane. The basis for these selections are outlined below.

2.2 Materials - Copper is eliminated as a material of construction since its relative weakness would require excessive cross bracing. The braces, in addition to increasing the material cost, would complicate the plan of the bottom of the platform to such a degree as to make efficient placement of cooling tubes and heating cable difficult. Copper is also relatively expensive, hence it rates poorly on most criteria.

The relatively low thermal conductivity of stainless steel would not significantly affect the temperature distribution of a stainless steel "platecoil" lunar plane on the cooling cycle; however, using this material would dictate that the heating elements be placed in the troughs of the corrugations. This placement would probably lead to excessive heating element coverage and cost to achieve a reasonable temperature distribution over the complete plane on the heating cycle. These disadvantages for a stainless steel platecoil on a heating cycle would apply to a plane fabricated of stainless steel plate on both the heating and cooling cycles.

As a basis of comparison, an approximate temperature difference of 7 R was permitted between the plate immediately above the heating (or cooling) element and the plate at a midpoint between any two adjacent elements. The maximum temperature difference across the complete plane will then be roughly this 7^{o}R plus the liquid nitrogen (or heating medium) temperature gain(or loss).

It appears that constructing the lunar plane of aluminum would be the proper selection. If the plane were fabricated of aluminum platecoil, the location of the heating elements would be limited, as in the above discussion of stainless platecoil. This would probably not be a major objection since a greater element spacing would be permitted to maintain the 7^{o}R temperature differential, due to the considerably higher thermal conductivity of aluminum. Based on availability and relative cost, aluminum plate is preferred over aluminum platecoil.

An electrical resistance heating system is recommended in Paragraph 2.3. Due to the high degree of size reduction by swaging the manufacturers of the required heating cable have advised that it is beyond the present manufacturing capability to supply and guarantee an aluminum sheathing free of minute cracks and imperfections. These sheathing flaws would permit the mineral insulator between the conductor and sheathing to outgas at rates intolerable to present design standards.

There is a possibility that higher quality aluminum sheathed cable will become available before the final designs are made. If aluminum sheathing continues to be unavailable, copper sheathed cable should be used. This alternative will require the design of a clamp to attach the copper cable to the plane and give adequate heat transfer in high vacuum surroundings.

The following Table VI-1 summarizes the relative advantages and features of the candidate materials considered. The recommended materials for the lunar plane and appurtenances are aluminum tubing welded to aluminum plate with concentric electric heating cable whose sheathing is dependent upon availability.

2.3 Heating and Cooling Systems - Four combinations of heating and cooling systems have been considered. An evaluation of the relative merits of these systems is shown on Table VI-2.

For the cooling system, only liquid nitrogen has been considered inasmuch as this refrigerant has been selected for the heat sink system.

For the heating system it has been concluded that both the hot water and steam heating schemes should be eliminated from further consideration due to problems of reliability, temperature continuity, drainage, control complexity, and relative cost. An infra-red heating lamp scheme should also be eliminated because it requires a large space and the reflectors would require a coolant system that would introduce possible leakage, drainage, and purge problems. The relative cost of the heating lamp system is also high. The heating cable of alternate 3 has a low space requirement, high reliability, relatively low control complexity, low first cost and no purge requirements. Alternate 3 is therefore recommended.

TABLE VI-1

LUNAR PLANE MATERIAL EVALUATION

ALTERNATES	1	2	3	4	5
PLATFORM	Aluminum Plate	Aluminum Platecoil	Stainless Steel Plate	Stainless Steel Platecoil	Copper Plate
NITROGEN TUBING					
Material	Aluminum	Intergral	Stainless	Intergral	Copper
Attachment	Welded	Welded	Welded	Welded	Brazed
HEATING CABLE SHEATH					
Material	AL or CU	AL or CU	S. S.	S. S.	CU
Attachment	Welded or Clamped	Welded or Clamped	Welded	Welded	Brazed
TEMPERATURE DISTRIBUTION					
Cooling	G	E	A	G	E
Heating	G	G	A	A	E
ZONABILITY	G	E	G	E	G
HEAT TRANSFER					
Cooling	G	E	P	A	E
Heating	AL Cable-E CU Cable-A	AL Cable-E CU Cable A	G	G	E
STRENGTH AT CRYOGENIC TEMPERATURES	G	G	G	G	P
RELATIVE COST	1.0	1.5	1.25	1.25	1.75

P - Poor, A - Average, G- Good, E - Excellent

TABLE VI-2

EVALUATION OF LUNAR PLANE HEATING & COOLING SYSTEMS

SYSTEMS -
1. Hot Water and Liquid Nitrogen
2. Steam and Liquid Nitrogen
3. Electric Heating Cable and Liquid Nitrogen
4. Infra-Red Heating Lamps and Liquid Nitrogen

ALTERNATE NO.	1	2	3	4
CONTINUITY OF TEMPERATURE VARIATION	P	P	E	E
ZONABILITY	A	A	G	E
RELIABILITY	P	P	G	A
HEATING SYSTEM PURGE	YES	YES	NO	YES[a]
INSTRUMENT INTERFERENCE	NONE	NONE	DConly	DConly
CONTROL COMPLEXITY	A	P	E	G
SPACE REQUIREMENTS	P	P	A	P
RELATIVE FIRST COST	2	3	1	4

a. Reflectors require cooling water.
P - Poor, A - Average, G - Good, E - Excellent

2.3 Lunar Plane Temperature Control - A study of the transient heating and cooling of the lunar plane has indicated the following:
a). Increasing the temperature of the lunar plane from 180°R to some value up to 720° R should not present any particular problem since the heating rate can be readily controlled by regulating the energy input to the heating elements.

b). Cooling the plane from 720° R to some value down to 180°R is considerably more difficult. Various alternate methods are available. Simply removing the electric power input to the heating elements and allowing the plane to radiate to the heat sink until the desired temperature is reached might be sufficient if the temperature drop were small or the time required to reach a given temperature were not important. The included curve shows the temperature-time relationship for natural cooling (Fig. VI-6).

If a large temperature drop in a relatively short period is required, two systems are feasible. The first system would utilize the radiation effect for some time based on the required temperature drop per unit time. When the radiation rate reached this minimum permissible rate, a calculated quantity of liquid nitrogen would be injected into the cooling system. On proceeding through the system this material would probably vaporize and, as a result of the two phase flow, different heat transfer coefficients and corresponding variations in the plate temperature would result. The temperature differences

would probably equalize themselves quite quickly by conduction through the plate. The cooling rate would then be a function of the radiation rate and the magnitude and frequency of the liquid nitrogen injections. This type of system could impress relatively large thermal shocks on the plane which would have to be carefully designed using special procedures such as internal stress relieving and radiographing of the completed unit. At best, this system would give a step type temperature vs time curve whose mean would be controlled with somedifficulty.

The final procedure would consist of a controlled temperature, nitrogen gas system to circulate gas through the liquid nitrogen piping for cooling purposes. The temperature gradient across the tube walls and, therefore, the plate cooling rate could then be more smoothly controlled. With this system the large thermal shocks could be avoided.

It appears from this study that continuous temperature control, as required by the Guidelines, would require a circulating gaseous nitrogen plant. A complete study oft he desirability of this requirement should be made before proceeding with final design of this system.

3.0 Cryopumps

3.1 Purpose - The purpose of the cryopump is to supplement the diffusion pumps at the low pressure end of the design vacuum range. The gas load will consist primarily of nitrogen and oxygen with some hydrogen, argon, carbon dioxide, and water vapor.

3.2 Operating Temperature - Cryopumping means providing a surface whose temperature is much lower than the saturation temperature corresponding to the partial pressure of a gas, causing its incident molecules to condense.

In order to pump nitrogen, argon, carbon monoxide and oxygen at the vacuum level desired, it is necessary to provide condenser surfaces at about 20°K. The vapor pressure of nitrogen at 20°K is 10^{-11} torr. With a cryosurface at this temperature and nitrogen at this pressure, a dynamic equilibrium exists in which the condensation and evaporation rates are equal. Hydrogen, helium, and neon will not condense at this temperature and must therefore be removed by diffusion pumps.

3.3 Materials Selection - The same material considerations apply to the cryopump panels as to the heat sink panels, with even stronger arguments in favor of aluminum in regard to brittle fracture.

3.4 **Design** - Since the cost of removing heat increases rapidly as the heat removal temperature decreases, the radiant heat load on the cryopump panels should be minimized. To accomplish this, the cryopump surfaces should "see" only liquid nitrogen cooled surfaces. The radiant heat load from an enclosure at 100°K will be about 1/80 of the load from a surface at 300°K, all other things being equal.

Temperature is not the only factor which must be considered in cryopump panel design. The molar flux (moles/cm²sec) incident upon the array is given by the kinetic theory of gases as

$$N = \frac{P}{\sqrt{2 \pi RTM}}$$

The rate of capture, N_c, is, by material balance, equal to the sum of the leaks, virtual leaks, outgassing and diliberate input. A coefficient C, known as the capture coefficient of the array is defined by

$$\dot{N}_c = C\dot{N}$$

The capture coefficient is a useful design parameter and can be determined by direct experiment. A second coefficient of considerable importance is the sticking coefficient, f, which is the faction of molecules impinging on a surface (not array) that is captured.

The distinction between the capture and sticking coefficient is important. The essential difference is that the sticking coefficient depends on the distribution of velocities and directions of the incident molecules and the nature of the surface while the capture coefficient depends, in addition, on the array geometry.

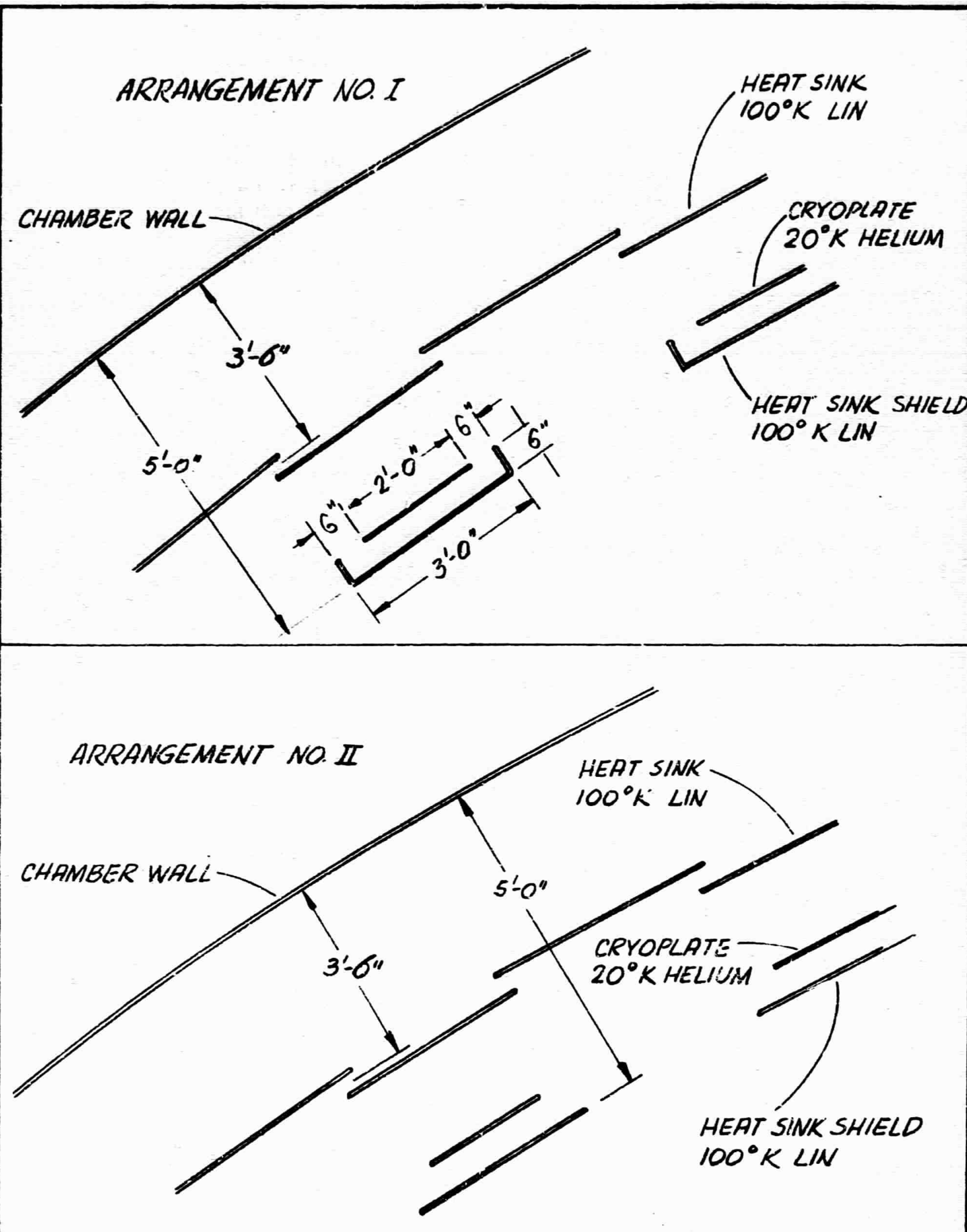
Attempts have been made to relate the sticking coefficient to other "Fundamental" parameters such as the thermal and kinetic energy accommodation coefficients, α_t, and α_k. Should these attempts prove successful, values of f could be calculated from the results of relatively simple thermal experiments. In the meantime, a reasonably reliable method of estimating capture coefficients is required.

It has already been mentioned that the cryopump panels are to be nitrogen shielded. Since the panel can only "see" nitrogen cooled surfaces, molecules must bounce on these surfaces at lease once before impinging on a cryopump panel. The velocity distribution will be characteristic of the geometric average of the shield temperature and the vehicle temperature, say 173°K, hence much of the energy

will be removed from the pumped molecules before they collide with a pumping surface. The sticking coefficient for the molecules that strike cryopump panels will probably be about 0.8. It has been determined by Monte Carlo calculations that a capture coefficient of about 0.31 results for an array having an open entrance fraction of 0.5 for the preferred design concept.

Figs. VI-1, VI-2, and VI-3 show several arrangements; the preferred design is that in Fig. VI-3.

3.5 Control Zones - The control zones for the cryopumping surfaces shall correspond to the control zones for the heat sink panels so that the two systems will operate in unison with varying radiation loads.



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SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NO NAS 9 - 413

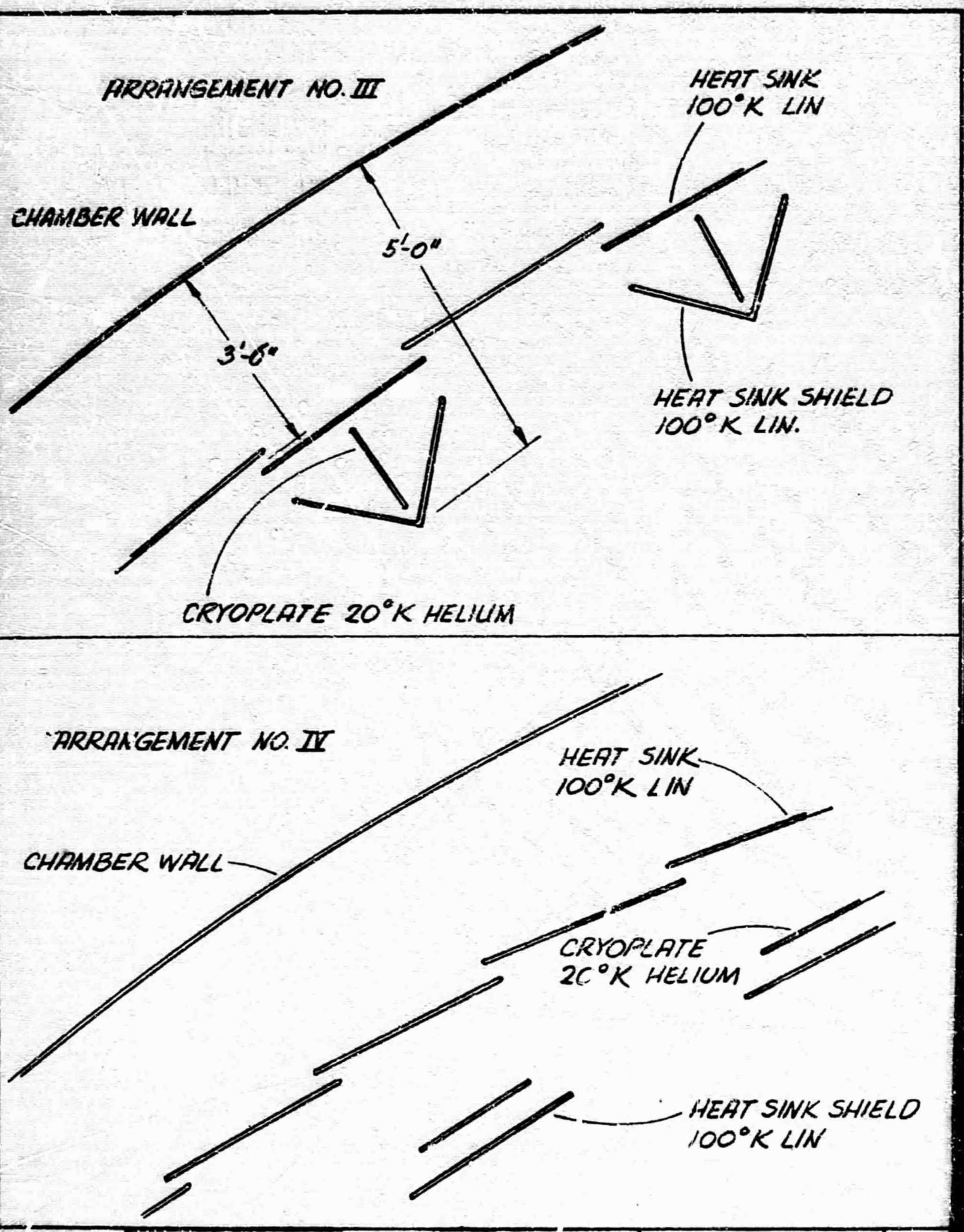
HEAT SINK & CRYOPUMPING CONFIGURATIONS

JOB No 4185

REV.

FIG. VI - 1

G-231-E 4-14-59 II



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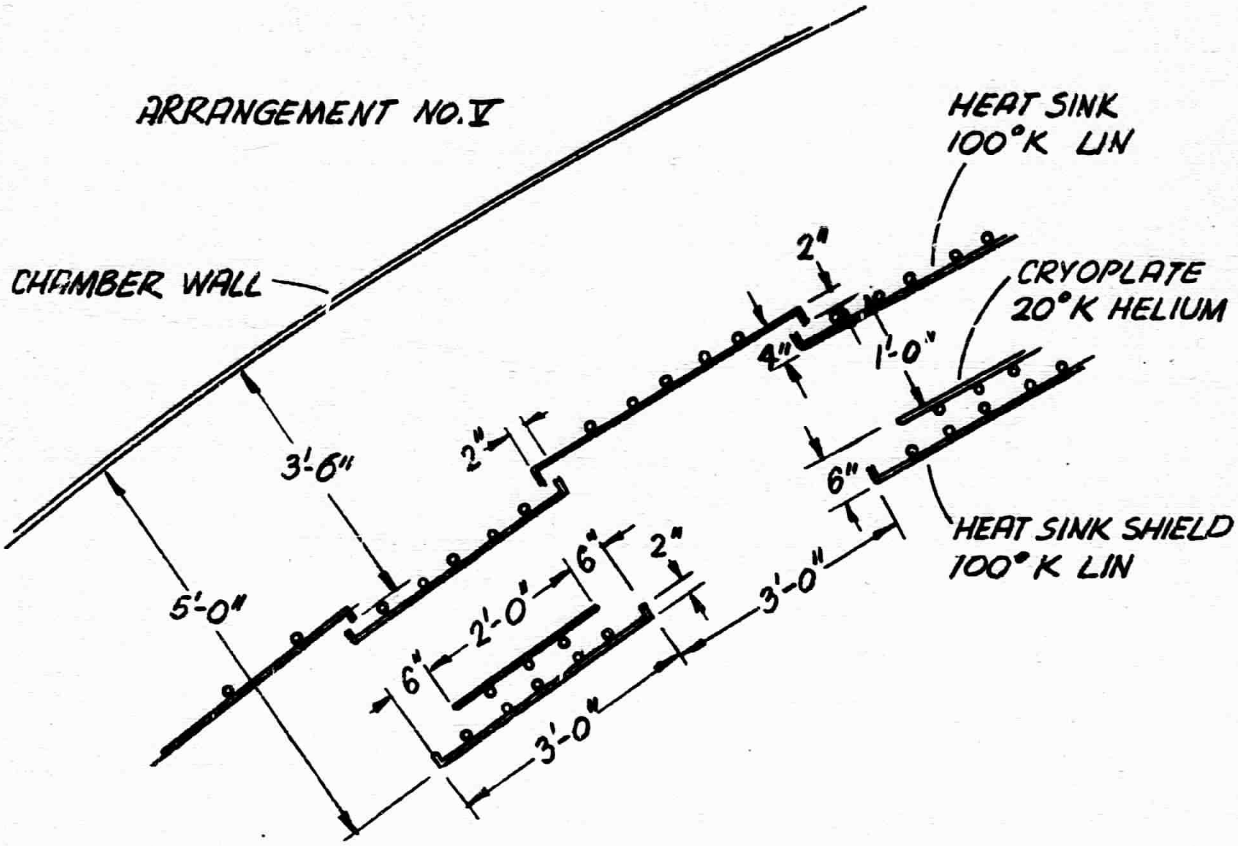
CONTRACT No NAS 9-413

JOB No 4185

HEAT SINK & CRYOPUMPING CONFIGURATIONS

FIG. VI-2

REV.



REV. | DESCRIPTION | ENG | DR | CHK | SUPV | MATL | APPROVALS | DATE
0

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PREFERRED HEAT SINK
AND CYROPUMP CONFIGURATION

JOB No 4185

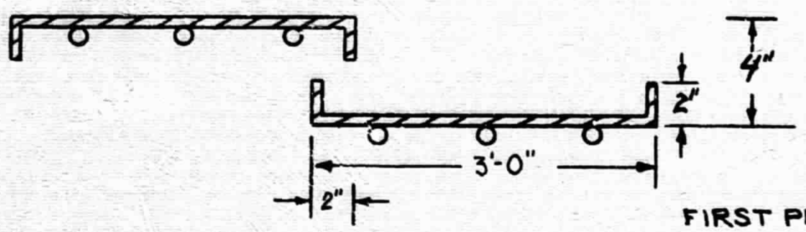
FIG VI - 3

REV.

G-231-E 4-14-59

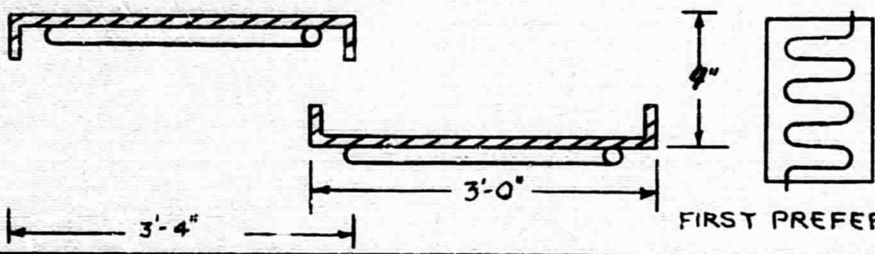
II

TYPE I - TUBE ON SHEET - STRAIGHT TUBES



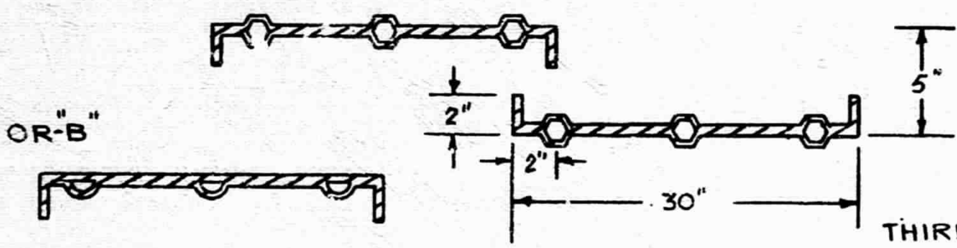
FIRST PREFERENCE

TYPE II - TUBE ON SHEET - SERPENTINE PATTERN



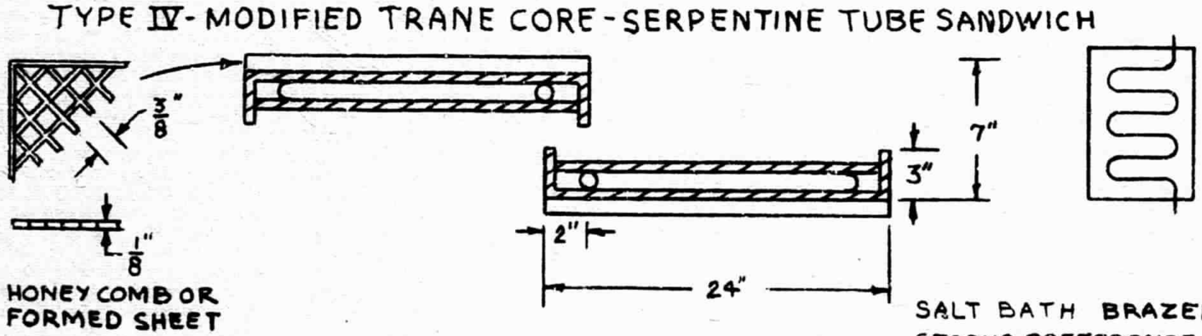
FIRST PREFERENCE

TYPE III - FORMED SHEETS - "A"



THIRD PREFERENCE

TYPE IV - MODIFIED TRANE CORE - SERPENTINE TUBE SANDWICH



SALT BATH BRAZED
SECOND PREFERENCE

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
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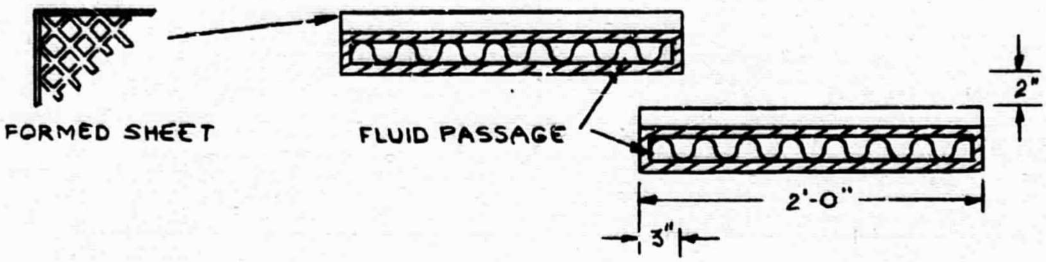
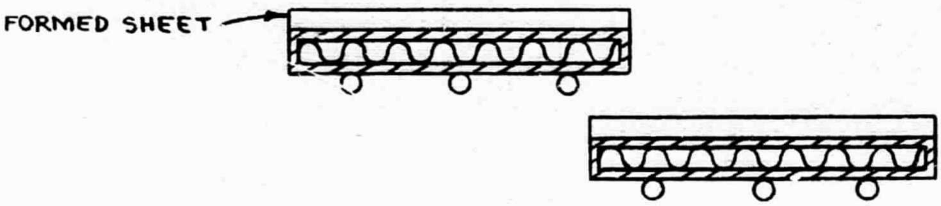
	CRYOPANEL DESIGNS	FIG. VI - 4	

G-231-E 4-14-58 II

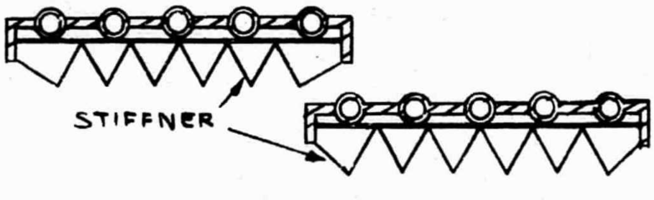
TYPE V - MODIFIED TRANE CORE "A" - HOLLOW CORE



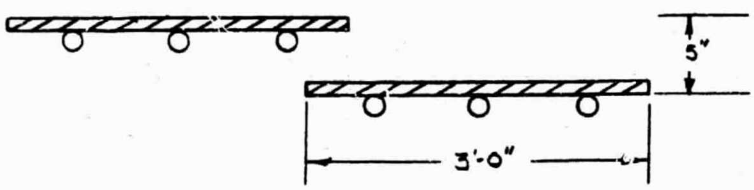
-MODIFIED TRANE CORE "B" - TUBE ON CORE.



TYPE VI - TUBE IN SHEET



TYPE VII - TUBE ON FLAT SHEET



REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
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JOB No 4185

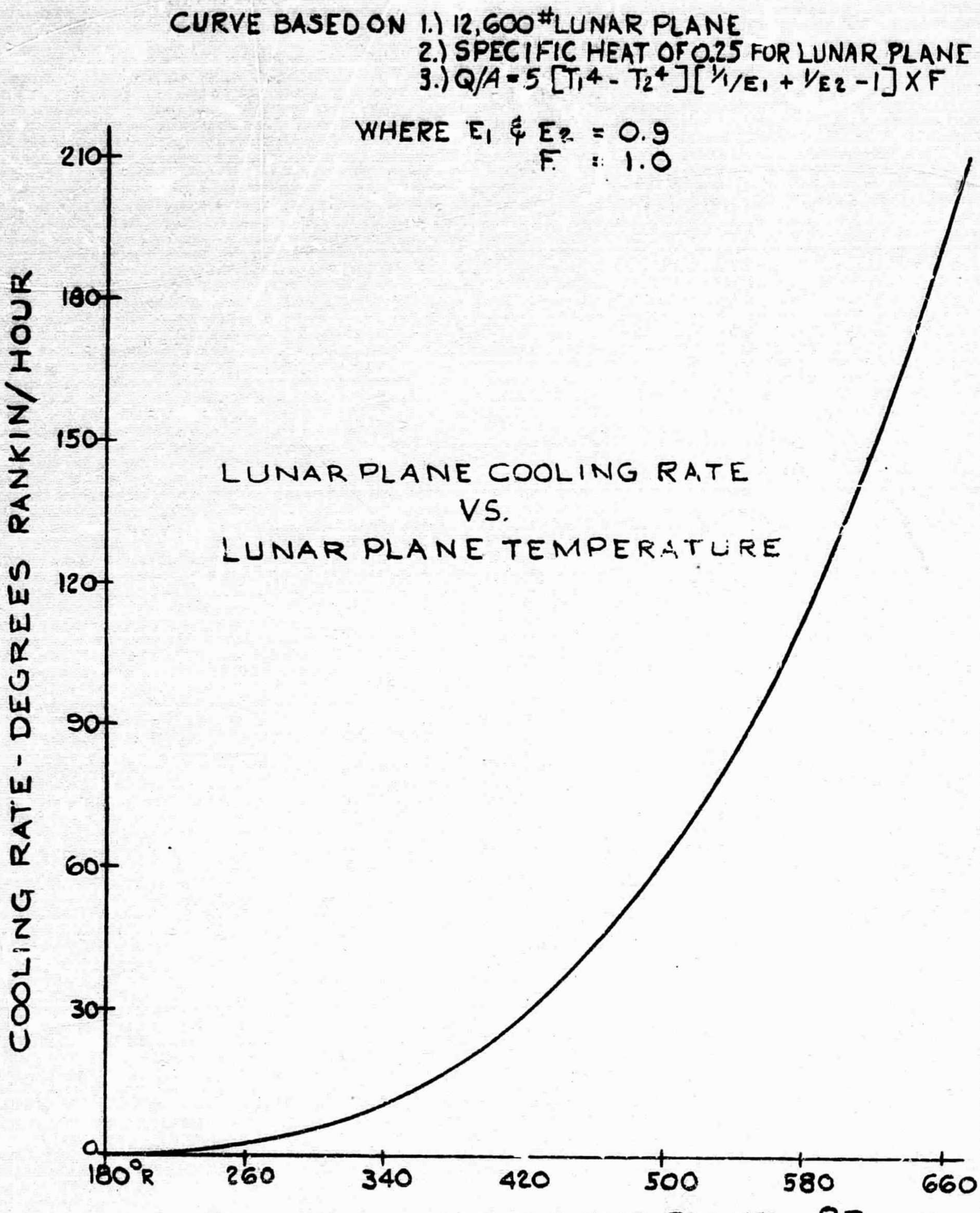
REV.

CRYOPANEL DESIGNS

FIG. VI - 5

II

G-231-E 4-14-58



CURVE BASED ON 1.) 12,600 # LUNAR PLANE
2.) SPECIFIC HEAT OF 0.25 FOR LUNAR PLANE
3.) $Q/A = 5 [T_1^4 - T_2^4][1/E_1 + 1/E_2 - 1] \times F$
WHERE E_1 & E_2 = 0.9
F = 1.0
COOLING RATE - DEGREES RANKIN/HOUR
210
180
150
120
90
60
30
0
LUNAR PLANE COOLING RATE
VS.
LUNAR PLANE TEMPERATURE
180°R
260
340
420
500
580
660
TEMPERATURE OF THE PLANE - °R

FIG. VI-6

SECTION VII
SOLAR SIMULATION

1.0 Introduction - The effect of solar radiation on a space vehicle can be simulated in a space environmental test facility by two principal methods: (1) A thermal flux simulator which irradiates a surface with infrared energy so that the thermal energy absorbed by the surface will be equivalent to the solar absorptance. This system generally uses quartz lamps located within the vacuum chamber as the source of energy. (2) A solar simulator irradiates a test vehicle with a collimated energy flux, equivalent to the solar flux, with similar spectral characteristics to the solar spectrum. The solar simulator radiation sources are usually located outside the vacuum chamber and the energy enters through portholes. The thermal flux simulator is compared with the solar simulator with respect to various characteristics in the next paragraphs.

2.0 Thermal Flux System

2.1 General Description - The thermal flux system utilizes tubular quartz heat lamps to produce a heating effect on the vehicle equivalent to 140 watts/ft^2 of sunlight. A similar but smaller system would be used to produce the heating effect of an earth albedo of 65 watts/ft^2 intensity on the opposite side of the vehicle. The lamps, each with its own compact reflector assembly, would be mounted inside the chamber. The lamp and reflector assemblies would be liquid cooled and the piping involved would be a part of the structural framework of the lamp mounts.

One array of lamps would illuminate the vehicle from the side over an area 40 ft by 13 ft and a second array would illuminate a 13 ft diameter circle from above. The albedo illumination from a third array would illuminate a 40 ft by 13 ft area. By mounting the lamps in close proximity to the vehicle, and by utilizing the flexibility of reflector design and arraying, a uniformity of $\pm$ 10% could be attained. The uniformity would, however, be dependent on the number of lamps lit, which would vary during the duration of a test due to lamp failures. The incident light would be virtually uncollimated, with a full cone angle of nearly 180°. Although the spectral energy distribution of the quartz lamp is radically different from that of sunlight, it would be possible to bring the vehicle to the desired equilibrium temperature as determined by previous thermal balance experiments.

2.2 Optical System - The tubular quartz heat lamps are not suitable sources for an efficient optical projection system due to their extensive length and relatively low energy density. For a short distance, such a line source could be projected by a parabolic or elliptical cylinder. Such a reflector would be placed behind the lamp and a small circular cylinder reflector placed in front to direct the forward emitted radiation back to the lamp and reflector. Fig. VII-1a shows the general intensity pattern which would be obtained from such a reflector. The intensity pattern is the convolution of the two distributions shown on Figs. VII-1b and VII-1c. Fig. VII-1b shows a cross section of the beam in a plane perpendicular to the line source.

The angular distribution may be adjusted in this plane by varying the focal length of the reflector, the only limitation being that of the size of the reflector. A 60^{o} full cone angle is practical both from the point of view of angular distribution and size. Fig. VII-1c shows the distribution in a plane parallel to the line source. In this plane, the reflector is effectively a plane mirror and the distribution is approximately the same as that of the direct radiation from the lamp. Due to this large angular distribution, the reflectors must be used in close proximity to the test object to avoid excessive spillover when combining the intensity patterns to obtain overall uniformity.

At a distance of approximately 2 ft from the test object, an estimated 25% - 35% electrical input to usable flux efficiency may be expected. The energy lost would be accounted for in radiation back to the lamps (shadowing), heating of the lamp mount and reflector, electrical losses and spurious radiation.

2.3 Number of Lamps Required - Due to differences in spectral absorptivity, the energy absorbed by a surface from one source may differ from that absorbed from another source of the same intensity. Assuming aluminum, copper, gold, and silver to be typical of the material used on the outer surface of most space vehicles, a comparison has been made of the energy absorbed by these metals from the sun and from a quartz heat lamp. For an approximation, the absorptivity of evaporated films of the metals and the black body distribution of a source at 5500^{o} C and 2100^{o} C were used for the sun and for the incandescent tungsten quartz lamps, respectively. The results of this comparison are summarized in the following table:

ABSORPTIVITIES OF VARIOUS MATERIALS

Source	Temp. Source	% Incident energy absorbed			
		Cu	Ag	Al	Au
Sun	5500°C	18.0	9.0	9.8	18.0
Incandescent Tungsten	2100°C	3.5	3.6	3.0	3.5
Solar absorptivity / W absorptivity		5.1	2.5	3.3	5.1

Since the absorptivity, for example, of aluminum for solar radiation is 3.3 times the absorptivity for incandescent tungsten, it would be necessary to increase the incident flux in a thermal flux system by a factor of 3.3. to insure that the energy absorbed would be equivalent to the solar absorptivity.

Based upon these values, a considerably higher intensity from the tungsten sources would be required to produce the heating effect of the sun with an intensity of 140 watts/ft^2. As a very conservative value, an intensity of 400 watts/ft^2 will be used in subsequent calculations as the equivalent intensity of the quartz lamps. A similar argument leads to 200 watts/ft^2 intensity for the albedo.

If 1000 watt quartz lamps (overall length - 14 inches) were arrayed in a semi-cylinder of 15 ft diameter and 40 ft high, concentric with the vehicle for the side sun and albedo, and in a 13 ft diameter circle for the overhead solar simulator, then the average lamp densities would be: (1) Overhead sun, 1.6 lamp/ft^2; (2) Side sun, 0.88 lamp/ft^2; and (3) Albedo, 0.44 lamp/ft^2.

Two alternatives are possible with such a configuration which would allow access to the vehicle and insertion and removal of the vehicle in the test position. One would be to hinge one or both of the lamp arrays so that it could be swung out of the way. Also, it would be possible to place the albedo simulator at a sufficient distance to allow the vehicle to be moved between it and the side solar simulator. As pointed out previously, however, this would result in a much decreased efficiency and in excessive heat loads on the shroud due to spillover. The former is, therefore, more desirable.

The above lamp density calculation for the side sun provides for a uniform intensity over the entire half of the vehicle. To produce the distribution equivalent to illumination by parallel radiation, it would be necessary to have a varying lamp density in the horizontal direction which is maximum at the vertical centerline of the array.

2.4 Lamp Configuration - Fig. VII-2 shows the location of the two solar thermal flux lamp arrays in position in the chamber. A large volume of coolant must be circulated through each array to maintain the lamps and reflectors at a suitable operating temperature. As indicated above by the 25% efficiency of the lamps, 75% of the total input must be dissipated by the coolant supplied to the lamps and by radiation to the shrouds.

The lamp reflector would be clamped directly to the coolant pipes in such a way as to provide a large area of contact for efficient heat transfer. A sketch of the pipes and reflectors is shown on Fig. VII-3.

2.5 System Evaluation - Although the reflector assemblies could be made quite compact, with the lamp densities required and the amount of cooling piping and electrical conductors required, the three thermal flux systems would produce a relatively solid shell around the vehicle which would shield it from the shrounds and negate their effect. The blocking factors for the three systems are: overhead - 50%, side sun - 27%, albedo - 13.5%. The added thermal load within the chamber would also be of considerable significance in the cost of the facility. Due to spurious radiation and also the radiation due to the ambient temperature of the lamp arrays, a considerable additional load would be placed on the LN_2 system alone. The cost of electrical and coolant penetrations would also become considerable.

The poor spectral distribution of the system would eliminate the possibility of performi- thermal balance tests in the chamber. The spectral distribution changes with intensity. The function of the facility would be further degraded by the lack of ultraviolet radiation from the source. This deficiency could be significant due to its effect, other than thermal, on a man or on materials.

Although these lamps have a usable life of the order of 1000 hours, lamp failure becomes a serious problem with the thermal flux system. Most of the surface of the vehicle will be illuminated primarily by one lamp only. Therefore, a lamp failure will result in a serious degradation in uniformity which cannot be corrected without breaking the test. It would be possible to make periodic changes of all lamps to decrease the incidence of lamp failure.

2.6 Upgrading - Upgrading the system in width of the test area would necessitate a rebuilding or extensive modification of the entire internal thermal flux system.

3.0 External Module Solar Simulator System

3.1 General Description - The external solar simulator module consists of a close-packed array of high pressure Xenon arc lamps and associated condenser optics. The radiation is projected through a window assembly onto the test area. The radiation beams from adjacent modules overlap in such a manner that the uniformity is preserved over the surface of the test vehicle.

The basic module is approximately 5 ft square and illuminates a 5 ft high by 6.5 ft wide portion of the test vehicle. The modules are stacked in two adjacent columns, 9 modules high, to illuminate the entire 13 by 40 ft test area. The module is accessible for servicing and lamp replacement during operation. Power supplies and other associated equipment will be located in racks adjacent to the modules.

The overhead solar simulator would be provided by four modules located on top of the chamber and projecting radiation downward to the 13 ft diameter test vehicle. These modules would be different from the side solar simulator modules.

The albedo would be given by a column of nine modules located on the side of the chamber opposite the solar simulator. The basic module would be the same as the solar simulator module, although the optical projection system would be slightly different.

The projection system would be designed to illuminate a 5 ft high by 13 ft wide section of the test vehicle with an intensity of approximately 65 watt/ft^2.

3.2 Heat Load - The radiation from the solar and albedo simulators is collimated and directed toward the test vehicle; consequently, only a small portion of the energy that enters the chamber falls directly onto the cryogenic panels. The major portion of the heat load associated with the simulator is dissipated by water and air cooling outside of the vacuum chamber.

The lamps used in these units have only recently become available in production quantities, and extensive information as to their proper operation in an optical collector system, from a thermal balance

viewpoint, is lacking. Extensive theoretical and experimental work on proper cooling methods have been undertaken for the 5 KW lamp collector assembly, and for the more extensively used 2.5 KW lamps. Preliminary indications are that approximately 80 CFM is required to adequately cool the 5KW lamp collector assembly. Provisions for properly manifolding and directing of the air streams will have to be devised so as to prevent the formation of local thermal gradients on the reflectors which could cause fracture by thermal shock.

A possible alternate solution is the use of all metallic reflectors in place of metal films on glass. This would alleviate the thermal shock problem and also permit a large amount of the heat load to be readily conducted away from the high intensity area. The main problem to be resolved with this approach is the collector efficiency loss incurred due to degradation of the optical surfaces of the collector mirrors when using metallic reflectors.

3.3 Performance - The radiation onto the test vehicle will have the characteristic of a high pressure Xenon spectrum. The Xenon spectrum closely resembles the solar spectrum except in the band between 0.8 and 1.0μ. In this band the relative energy of the Xenon lamp is greater than the solar spectrum. The radiation will be incident onto a point on the test vehicle from a direction contained within a square-based pyramid of apex half-angle of less than 10° in the horizontal and vertical directions. The intensity of illumination over the surface of the vehicle will be uniform to 20% rms.

3.4 Upgrading Potential - The external module solar simulator can be upgraded to a larger test area by adding modules to increase the height or width of the illuminated area to accommodate a larger test vehicle. Similarly, the albedo can be increased by adding additional columns of modules.

3.5 Lens Material - In order to keep the solar simulator costs at a minimum compatible with the functional requirements of the system, an investigation of the various available lens materials was made.

The least expensive material for use as lens material for this system is optical grade glass. As this material will not transmit the ultra-violet portion of the solar energy, requirements for cooling the lens assembly would have to be provided. In addition, any further upgrading of the solar spectrum would require the complete replacement of the optical system.

As an alternate, it is recommended that industrial grade fused silica of fused quartz be used as the lens material. This material is transparent to nearly all the radiation incident upon it, thus eliminating the necessity of cooling the lens array. Although the industrial grade is almost equivalent to the optical grade for this application, the price is approximately one-fourth as much as for the optical grade.

3.6 Flux Intensity Control - The Guidelines specify that flux intensity be variable from 25 to 140 watts/ft^2. One method of achieving this is to use a remotely controlled, variable, aperture located in the output light beam path of each module. A more economical method of varying the intensity is to shut down lamps and/or decrease the output from each lamp. (The 5 KW lamps are capable of being operated at half-intensity without a shift in spectrum). Besides cutting down initial installation costs the lamp life is greatly prolonged by running them at reduced output.

3.7 Performance of System - A first order optical analysis of the solar system indicates that the following performance characteristics will be achieved:

3.7.1 Collimation - Maximum of 10° half-cone angle, depending upon vehicle size. The collimation angle is a function of the distance of the vehicle from the optical system and the area being irradiated by the light beam.

3.7.2 Uniformity of Illunimation - The rms deviation of the illumination will be approximately 20% of the mean over the area of illumination. (Any improvement in uniformity of illumination of the system would have to be accomplished by reduction in the overall system efficiency, i.e., using only the nucleus portion of the high energy light source).

4.0 Comparison of Thermal Flux System to External Module Solar Simulator

4.1 Incident Solar Flux - In order to simulate the conditions in space, it is necessary that the energy absorbed by the surface in the simulator be equivalent to the solar absorptance. However, since most practical materials have different absorptivities for quartz lamps and solar radiation, it is necessary to compensate for this factor by increasing the incident thermal flux substantially in order to achieve the same absorbed energy. However, under this mode of operation, the thermal load on the cold shroud also is substantially increased.

The proper absorptivity for a thermal flux system could be achieved by coating the surface of the space vehicle with an appropriate material. However, any coating would affect the emissivity in the infrared. Thus, the re-radiated energy would be incorrect and an erroneous equilibrium temperature would be obtained.

The solar simulator irradiates the test vehicle with not only the same energy flux as the sun, but also a similar spectral distribution. Consequently, the surface of the test vehicle would absorb approximately the same energy as it would in sunlight.

4.2 Spectral Distribution - The spectral distribution of a quartz lamp used in a thermal flux simulator is shown on Fig. VII-4. The maximum emission occurs at approximately $1.2\,\mu$ for a filament temperature of $2200^{\circ}C$. Since the emissivity of quartz approaches unity in the infrared, there would be substantial emission from the quartz envelope in the infrared beyond 4 .

The expected spectral distribution from a 5 KW Xenon high pressure arc is also shown on Fig. VII-4. This lamp would be employed in a solar simulator. There is substantial similarily between this lamp and the solar spectrum.

4.3 Collimation - The collimation from the thermal flux simulator is undefined, since radiation is incident onto the test vehicle from a very large solid angle. No shadows would be formed by a thermal flux system. Without the formation of shadows, no thermal gradients and commensurate stress patterns would form.

The solar simulator would irradiate the test vehicle from a set of discreet locations; consequently, the shadow formation would be very good except in regions where radiation from two or more sources overlap.

The simulated solar radiation would appear to a point on the surface of the test vehicle as if it came from a source of approximately 1.5° half-cone angle; however, these source directions would be contained within a square-based pyramid of apex half-angle of less than 10° in the horizontal and vertical directions.

Better collimation on the test vehicle can be achieved; however, this improvement would be obtained at the expense of internal collimating optics or a greater distance between the source and the test vehicle.

4.4 Uniformity - Uniformity of illumination on the test vehicle can be achieved with a thermal flux system by the superposition of the radiation from one lamp and the nearest neighbors. If a lamp burns out a substantial portion of the radiation is affected.

Uniformity of illumination over the surface of the test vehicle can be obtained with a solar simulator by the super-position of the radiation beams from one or more modules. Since a number of Xenon arc lamps from each module illuminate each portion of the test vehicle, a failure of one lamp would cause only a fractional decrease in energy. Furthermore, since the lamps are located external to the vacuum system, they can be replaced while the system is in operation.

5.0 Summary Evaluation - The table on the following page summarizes the comparison between internal and external flux simulators.

6.0 Conclusion - The thermal flux system requires extensive internal equipment and it would be extremely complex in operation to obtain thermal conditions on the test vehicle corresponding to conditions expected in space. A major portion of the input electrical energy is converted into radiation which does not fall on the test vehicle and must be dissipated by the cryogenic panels, or other internal cooling equipment. By contrast the solar simulator is more complex, but provides thermal conditions on the test vehicle corresponding to conditions expected in space. Furthermore, the source of radiation for the solar simulator is an external module which can be serviced in operation. The major portion of the heat load is outside the chamber, with only a small fraction of the energy being wasted on the cryogenic walls.

All factors being considered, it is concluded that the external module solar simulator system should be employed.

COMPARISON OF INTERNAL THERMAL FLUX RADIATORS WITH EXTERNAL SOLAR SIMULATION

REQUIREMENT	THERMAL FLUX	SOLAR SIMULATOR
1.0 RADIATION CHARACTERISTICS		
1.1 Intensity	Yes	Yes
1.2 Collimation	Poor	10^{o} half angle
1.3 Spectral Simulation	Poor	Good
2.0 PHYSICAL CHARACTERISTICS		
2.1 Uniformity (on surface of vehicle)	Fair	10 - 20% rms
2.2 Radiation falling on cryogenic panels	High (3 x vehicle load)	Low (0.25 vehicle load)
2.3 Internal area of chamber wall required for system	Large	Negligible
2.4 Spurious Radiation	Large	None
2.5 Shadow formation on arbitrary vehicle shapes	None	Good
2.6 Prior environmental testing to establish proper radiation level	Substantial	None
2.7 Location of components requiring servicing	Internal	External
2.8 Location of potentially hazardous components (lamps, wiring)	Internal	External
3.0 UPGRADING POTENTIAL (Versatility)	Intensity only	Good (intensity spectrum area illum.)
4.0 MAINTENANCE DURING OPERATION	Internal (impractical)	External-Routine oper. procedure
5.0 PHYSIOLOGICAL CHARACTERISTIC OF SOLAR SIMULATOR	Some	Good
6.0 PHOTO-CHEMICAL VACUUM COLD INTER-RELATIONS ON TOTAL VEHICLE	Some	Good
7.0 FISCAL CHARACTERISTICS		
7.1 Installation		
7.1.1 Optical & Power supply (Relative)	Low	Significant
7.1.2 Other related equipment	Large cryo system	Min.. cryo system
7.2 Operation		
7.2.1 Solar Simulator	Minimum	Lamp replacement
7.2.2 Other related equipment	Large cryogenic consumption	Min. cryogenic consumption

7.0 Further Investigation Of Absorptivity - Further investigation of the absorptivity of several materials extended the previous comparison between solar radiation and tungsten lamps to include a comparison of xenon lamps. This work confirmed the previous calculations for tungsten lamps and incorporates new results for finished surfaces. It was completed late in the study and is appended to the foregoing analysis for completeness.

Table VII-1 gives the absorptivity of four evaporated metals with the sun, an incandescent tungsten lamp, and a Xenon compact arc lamp as the sources. The spectral energy distributions for a black body at 5500°C and one at 2100°C were used for the solar radiation and incandescent tungsten respectively. An actual distribution curve of a 1600 watt Osram Xenon compact arc lamp was used for the Xenon source.

While evaporated films of these materials are not necessarily expected to be the outer surface of a vehicle, their optical properties are generally typical of all metals. They all exhibit an increasing absorptivity towards shorter wavelengths. This characteristic is indicated in the table by the greater absorptivity with sources peaked toward the visible and ultraviolet spectral regions. Solar radiation has a higher ultraviolet content than either of the other two sources and therefore, is absorbed to a greater degree than the Xenon or tungsten radiation. The radiation of the Xenon arc is peaked considerably more toward shorter wavelengths than that of the tungsten source and so it will be absorbed to a greater degree by the metals. The one exception to this is in the case of Ag which has a uniformly high reflectance throughout the visible making the ultraviolet energy a more significant factor.

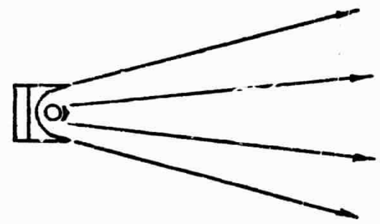
Table VII-2 gives similar information for painted and finished surfaces. Here the actual curve for sunlight by Johnson was used to determine the solar absorptivity of the materials.. Unfortunately, sufficient information is not available to permit a comparison of the absorptivity of these materials with incandescent tungsten.

TABLE VII - 1. ABSORPTIVITY COMPARISON FOR METALS

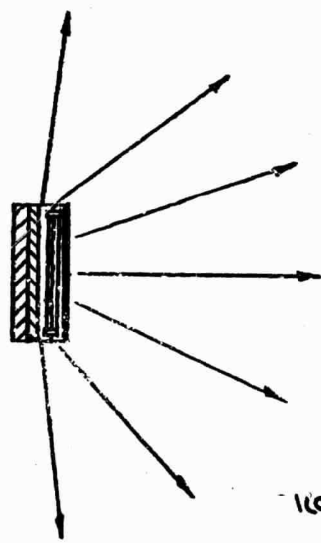
SOURCE	Al		Cu		Ag		Au	
	α	$\frac{\alpha_{sol}}{\alpha}$	α	$\frac{\alpha_{sol}}{\alpha}$	α	$\frac{\alpha_{sol}}{\alpha}$	α	$\frac{\alpha_{sol}}{\alpha}$
SOLAR RADIATION	.098	1	.180	1	.090	1	.180	1
INCANDESCANT TUNGSTEN	.030	3.3	.035	5.1	.036	2.5	.035	5.1
XENON ARC	.096	1.02	.128	1.4	.032	2.8	.142	1.3

TABLE VII- 2. ABSORPTIVITY COMPARISON FOR FINISHED SURFACES

SURFACE FINISH	α_{sol} (SOLAR RADIATION)	α_{xe} (XENON ARC)	$\frac{\alpha_{sol}}{\alpha_{xe}}$
RUTILE GRAY SILICONE PAINT	.826	.828	.997
RUTILE WHITE SILICONE PAINT	.186	.151	1.23
ALUMINUM SILICONE PAINT	.230	.236	.974
GOLD PLATED ALUM. - MIRROR FINISH POLISH	.219	.164	1.33
ALUM. - BRIGHT COMMERCIAL BUFF	.168	.169	.994



1(b)



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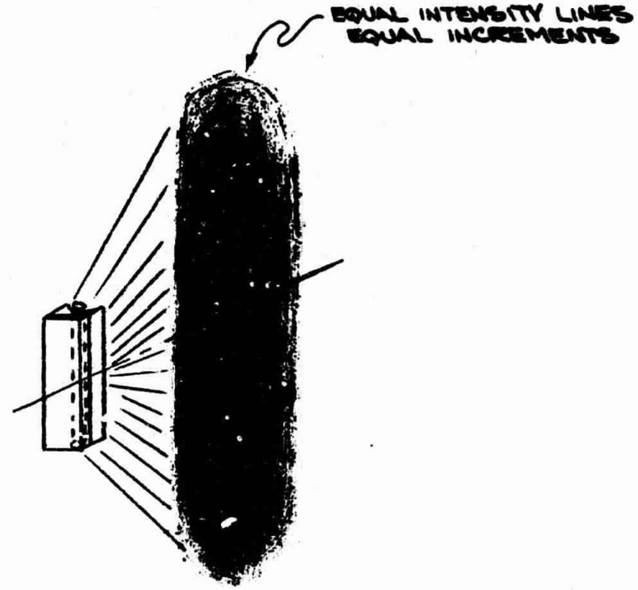

FIG. 1(a)

NASA-MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT Nº NAS-9-419

INTENSITY PATTERN
QUARTZ LAMP

BECHTEL CORPORATION
POWER AND INDUSTRIAL DIVISION

JOB No 4135

DWG NO

FIG. VII-1

SCALE NONE

REVISION

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
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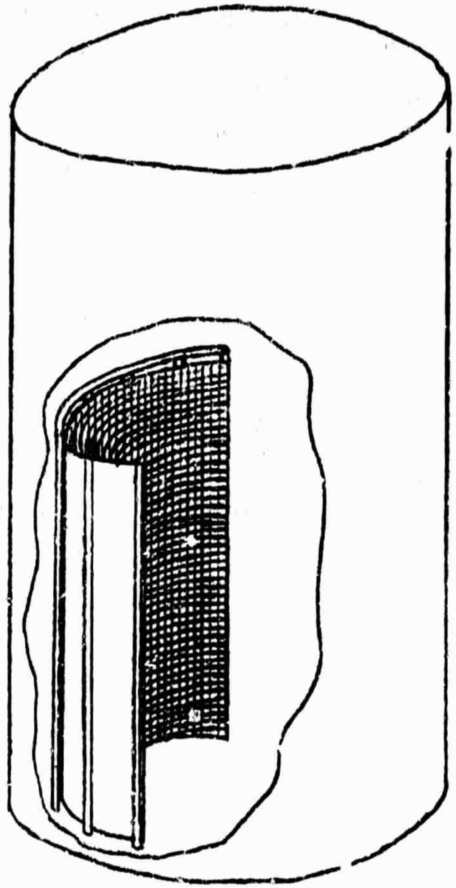

FIG. 2

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT Nº NAS - 9 - 419

LOCATION OF QUARTZ LAMP ARRAY

BECHTEL CORPORATION — POWER AND INDUSTRIAL DIVISION

JOB No 4185 — SCALE NONE — REVISION

DWG NO FIG. VII-2

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVAL	DATE
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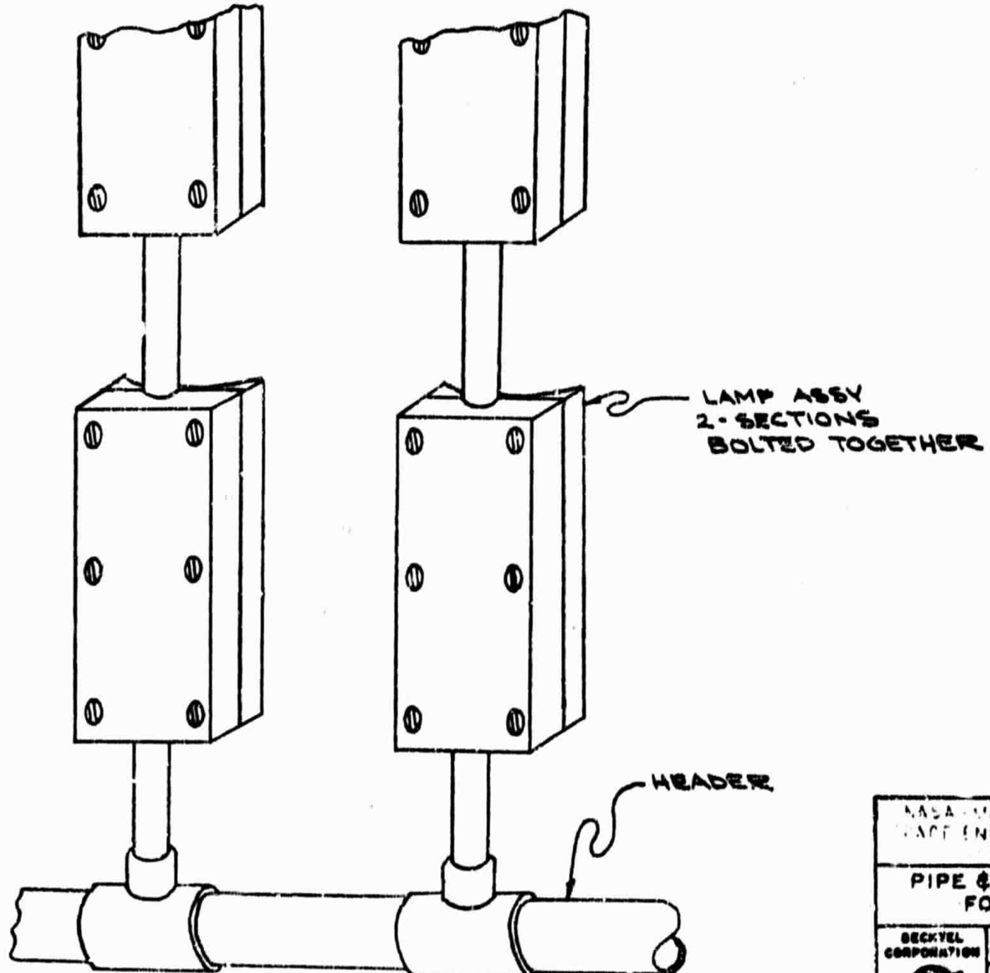

FIG. 3

NASA-MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY PIPE & REFLECTOR ASSEMBLY FOR QUARTZ LAMP			
BECKTEL CORPORATION POWER AND INDUSTRIAL DIVISION	JOB No 4185	SCALE NONE	
	DWG NO F.G. VII-3	REVISION	

REV.	DESCRIPTION	ENG	DR	CHK	SUP'V	MAT'L	APPROVALS	DATE
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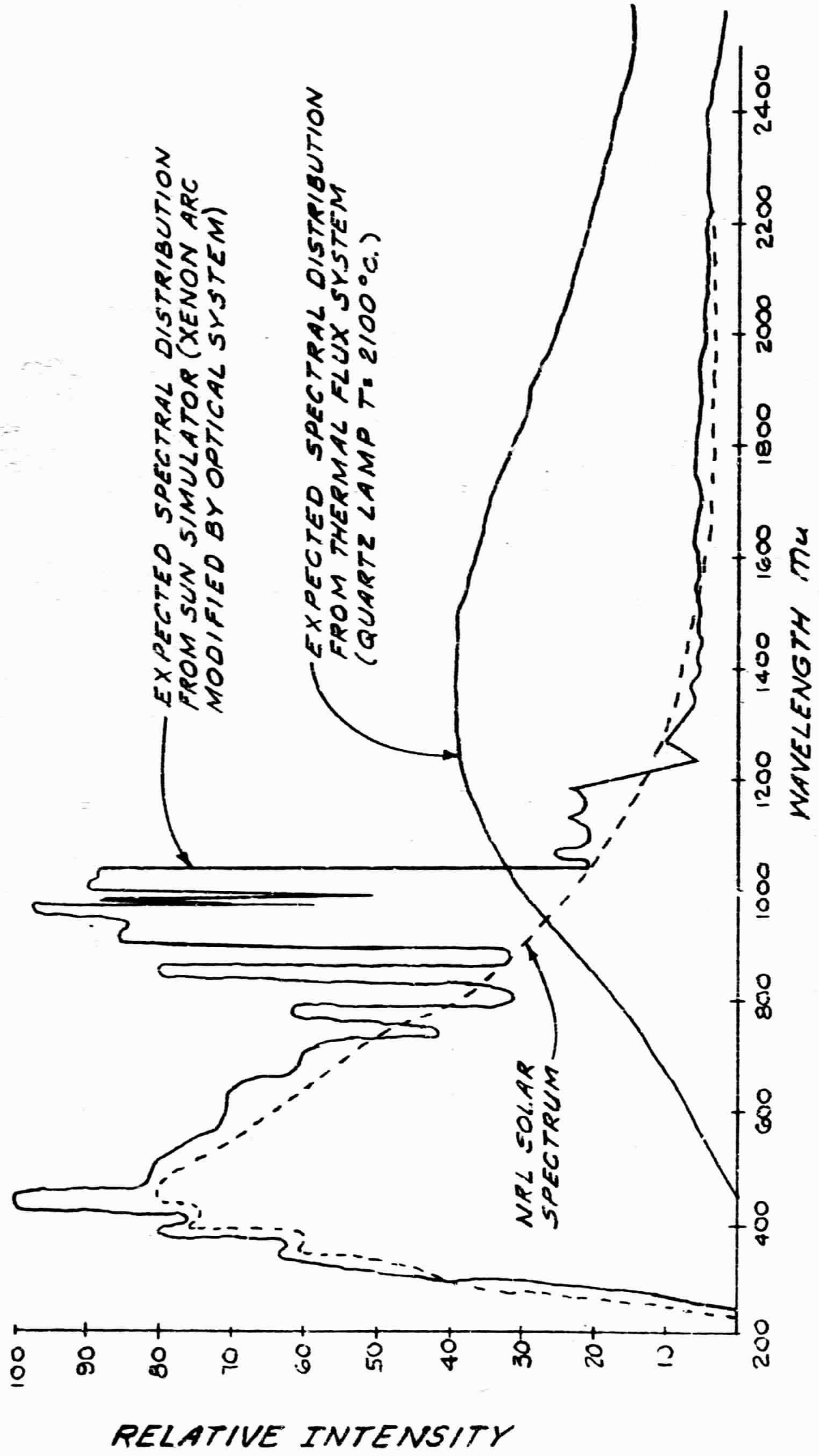


SPECTRAL DISTRIBUTION OF XENON ARC

II

FIG VII-4

SECTION VIII
REFRIGERATION

1.0 Determination of Thermal Loads on 100°K Surface - The load expected on the refrigeration system is the factor determining the equipment size, cost, etc.

1.1 Heat Leak

1.1.1 General - Of the possible modes of heat transmission to the refrigerated surface, only radiation is important. Convection accounts for only 1/27th of the total heat transfer at 10^{-3} torr and is insignificant at the design pressure (NTN-7). Conduction can be reduced to negligible proportions by proper design of the panel support structure. Support members should be long enough to reduce the thermal gradient to a point where the rate of conduction from the outer shell becomes negligible. This is most easily accomplished by using tension members wherever possible. In the event that compression members are required, they should be of thinwall tubing or stacked disc type. Adequate support systems can be fabricated from the usual cryogenic structural materials--copper, aluminum and stainless steel. Stainless steel is preferable because of its low thermal conductivity and high strength. Shorter members can be employed if terminations are not welded; for example, tubes can rest in sockets and wires can be fastened using hooks and eyes.

The radiant heat load is calculated using the Stefan-Boltzmann equation to estimate the net flux from the outer shell to the heat sink. This load can be considerably reduced by placing radiation shields between the sink and the outer shell. Shields of high emissivity are ineffective so that dew point calculations should be made. Shield temperatures are calculated by writing a general formula for radiant transfer from the i-th to the $(i \neq 1)$ th shield and applying the constraint that the shield-to-shield flux is the same for all adjacent shields. The thermal flux is reduced by a factor $1/(n \neq 1)$ when n shields are used.

1.1.2 Insulation - Heat passes through the chamber walls into the LN_2 heat sinks at a rate of about 14 BTU/hr ft^2 for an uninsulated vessel. This amounts to a load on the heat sink reliquifaction plant of about 130 KW for Chamber A. In order to reduce this as much as practicable, insulation can be provided between the heat sink panels and the inside of the chamber wall. Reflective insulation such as multiple layers of polished aluminum or an aluminized material such as NRC-2 would reduce the rate of heat leakage to about 1 BTU/hr ft^2. LN_2 and Helium lines are similarly insulated within

the chamber. However, heat-leaks around the various diffusion pump inlets and cryogenic piping penetrations will increase the in-leakage to a total of about 35 KW, and this is the basis of the heat leak component for Chamber A.

Insulation could be effectively applied to the exterior surfaces of the chambers, however, the space required, weight, cost, and installation complexity would be greater than for reflective insulation on the inside, where advantage of the high vacuum can be taken in the application of insulation. In addition with insulation on the outside, chamber walls would have to operate at reduced temperatures possibly requiring the use of nickel alloy steel for stiffeners. An additional factor which favors the use of a reflective type of insulation on the inside is the fact that its effectiveness diminishes as the chamber is repressurized thus permitting a more rapid warm up of the chamber. Insulation applied to the outside would have a constant efficiency for all conditions existing within the chamber. With the radiation barrier type of insulation between the vessel wall and the heat sinks, the vessel shell temperature is not expected to differ from ambient temperature by more than about 5°F.

1.2 Vehicle - Specified by guidelines.

1.3 Solar and Albedo Simulation - This load is determined by simulator equipment as outlined in Section VII.

1.4 Lunar Plane - This source of radiant energy can be determined, from the Stefan - Boltzmann equation. The magnitude depends on the temperatures of operation, the area of the plane, and view factors between the plane and heat sinks.

1.5 Motor - The power required to move the lunar plane and the vehicle must be absorbed by the heat sink when in operation.

THERMAL LOADS FOR LN_2 (KW)

Chamber Operation	A Lunar Landing	A Earth Orbit	B Lunar Landing	B Earth Orbit	D
Heat Leak	27	35	6	8	4
Vehicle	4	4	4	4	
Solar Simulator	21	95	5.25	5.25	
Albedo	--	48	--	--	
Lunar Plane	240	--	63	--	
Motor	--	30	--	--	
Subtotal	292	212	78.25	17.25	4
Pump Work	18	13	4.75	1.75	.25
Total	310KW	225KW	83KW	19KW	4.25KW

2.0 Determination of Thermal Loads 20°K Surfaces

2.1 Heat Leak - As with the 100°K surface, conduction losses can be reduced to negligible proportions by proper design of the panel support structure and similar precautions should be taken. The total heat load is calculated by standard procedures and the effect of condensation is found to be negligible.

The radiant heat load ismade up from two sources, a) direct radiation from 100°K panels and, b) reflected radiation from sources that the 20°K panels can not see directly such as the solar simulation lamps.

2.2 Thermal Loads for 20°K Surfaces in Chamber A (KW)

Source/Operation	Lunar Landing	Earth Orbit
Direct Radiation	1.2	1.2
Indirect Radiation	3.9	2.2
Contingency	2.4	2.4
Total	7.5 KW	5.8 KW

3.0 Plant Concepts

3.1 100°K Refrigeration System - Fluids that could be used for 100°K service are nitrogen, carbon monoxide, oxygen, neon, hydrogen, and helium. Neon and helium have large makeup costs. Hydrogen and

oxygen present some difficult safety problems. Carbon monoxide is toxic. Nitrogen is inert, readily available in liquid form for makeup and emergency operation; hence it is the recommended refrigerant for the 100°K surface.

It has been found in practice that large systems using boiling liquids are prone to develop hot spots as a result of vapor binding; also large tubes are required to accommodate two phase flow if the pressure drop is not to be excessive. For these reasons, the heat sink coolant should be liquid nitrogen.

Liquid should be produced in a liquifier and then transferred to the chamber under pressure so that it is subcooled. After leaving the chamber, the liquid is flashed back into the liquifier phase separator. The liquid returns to the coolant passages and the vapor is reliquified. In the event that makeup or more refrigeration capacity is required for a particular experiment, liquid nitrogen is added to the phase separator or refrigerator liquid storage tank while vapor is vented from the warm end of the refrigerator. Thus, relatively little of the available refrigeration in the purchased liquid is lost.

A schematic flow diagram of the liquid nitrogen reliquifier is shown on Figure VIII-1.

3.2 20°K Refrigeration System - The possible refrigerants at 20°K are helium and hydrogen. Helium is preffered from safety considerations.

The cycle for 20°K refrigeration is very different from that of the nitrogen refrigerator. The normal boiling point of helium is 4.2°K and the latent heat of helium is very low. These facts together with the increased cost of refrigeration at so low a temperature precludes the use of liquid helium. Helium at moderate pressure approaches the liquid density and the thermal conductivity of gaseous helium is high; consequently, the heat transfer characteristics of dense, gaseous helium are good. Because the J-T inversion temperature of helium is very low, a helium refrigerator must use an auxiliary hydrogen refrigerator or an expansion engine. Having already ruled out a hydrogen cycle, it is concluded that the helium cycle should be based on refrigeration using an expansion engine.

A schematic dense gas flow diagram of the helium refrigeration plant is shown on Figure VIII-1.

4.0 Economic Analysis - Because of the variation in refrigeration required of the nitrogen system, the refrigeration capability should be sized to handle the main load of all the chambers operating at the same time. The LN_2 required for peak loads would be trucked in and stored. This same storage could be used to back up the N_2 refrigerator in case of mechanical failure or some malfunction.

The anticipated testing schedule as it affects down time and refrigeration loads has a profound influence on the capacity and the process cycle of the liquid nitrogen refrigeration plant. For long test periods at high heat loads the reliquifaction plant as described above is preferred. For short test periods and relatively long down periods an air plant producing liquid nitrogen which is then stored for subsequent use could well be preferred. Before a refrigeration plant is finally designed, a reexamination should be made of a detailed test schedule to confirm the design basis.

Several different financing possibilities exist, such as direct purchase, leasing on site, leasing off site, and purchasing bulk LN_2. The following charts present typical costs for these alternatives. The refrigeration capacity of 250 KW was assumed early in the study as the basis of the economic analysis and does not correspond to the final calculated loads for the Chambers A and B complex.

LIQUID NITROGEN REFRIGERATION

Chamber Operation - 7000 Hours Per Year
Average Load = Heat Leaks + 60% Total Solar + 10% Lunar Plane + "B" & "D" = 295 K. W.
Peak Load = "A" Maximum Lunar Plane + "B" & "D" = 486 K. W.

	NASA-OWNED	NASA-LEASED		Private-Owned		Boil-Off
Size - Reliq. Plant	250 KW	250 KW		Max. Req'd. Plus		0
Capital Invested	$2, 300, 000	0		0		$445, 000
Annual Oper. Cost						
1 - Plant Oper.	$ 325, 000	$ 325, 000		0		$ 62, 000
2 - Make-Up	$ 287, 000**	$ 287, 000**		0		$1,863, 000
3 - Lease Charge	0	Lease $642, 000	Lease Buy $642, 000	On-Site $828, 000	Off-Site $1, 096,000*	0
4 - Total Oper. Cost	$ 612, 000	$1, 254. 000	$1, 254, 000	$828, 000	$1, 096,000	$1, 925, 000

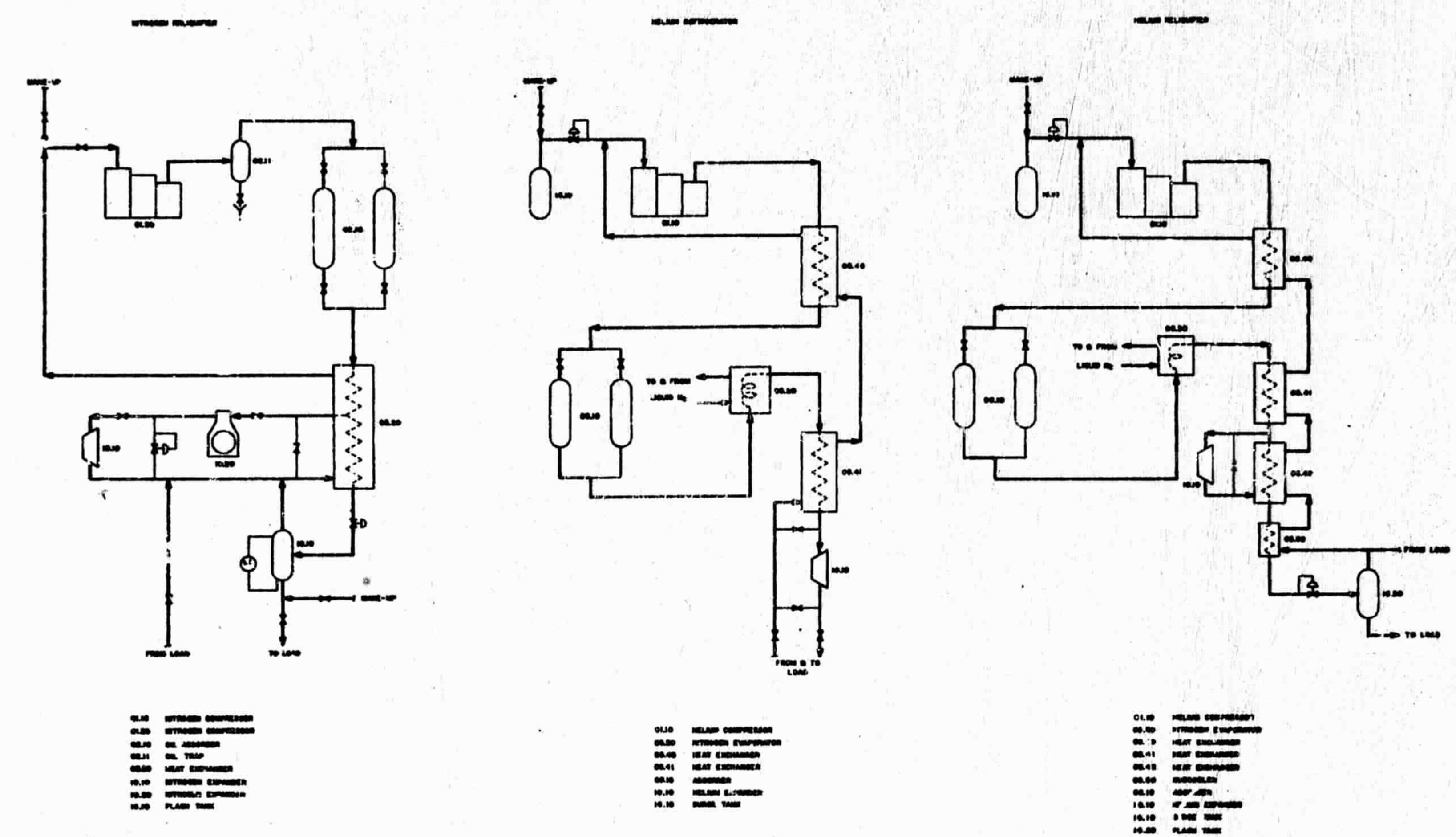
** Make-up = Loss + Avg Peak Loads - 250 K. W. *Piped
" " = 47 K. W.
" " 6, 600 Tons N_2/7000 Hrs.

HELIUM REFRIGERATION

Chamber Operation - 7000 Hours Per Year

	GASEOUS HELIUM 20 K. W. - 20°K	
	Nasa - Owned	Nasa-Leased
Capital Invested	$2,000,000	0
Annual Oper. Cost		
1 - Plant Oper.	$ 252,000	$ 252,000
2 - Make - Up *	$ 440,000	$ 440,000
3 - Lease Charge	0	$ 559,000
4 - Total Oper. Cost	$ 692,000	$1,251,000

*Make-Up = Leakage Loss



AIR PRODUCTS AND CHEMICALS, INC.
ALLENTOWN, PENN.

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

SCHEMATIC FLOW DIAGRAM
REFRIGERATION

4185 FIG VIII-1

II

SECTION IX

MAN RATING

1.0 Introduction - Planning and development of space vehicles and satellites requires that evaluation and proof of equipment reliability be checked under simulated space environment conditions. Every space flight is an extremely expensive undertaking and flight failure not only results in a serious economic loss but also loss of valuable technical data, flight equipment, launch equipment, and time. With the advent of manned space flight, proof of a vehicle's capability is a rigid requirement if loss of human life is to be avoided.

To insure adequate checkout of complete manned space systems, it is mandatory that man be tested as an integral part of the entire vehicle system. In order to accomplish such testing, it is necessary to subject man to environmental conditions equivalent to those to be expected in outer space. It is therefore necessary that adequate design consideration be given to insure that all possible precautions are taken against loss of life during ground-based testing. The application of such features to the design of space environmental simulation chambers is called "man-rating".

"Man-rating" entails consideration of the characteristics of viability and performance of humans, and the most critical design constraints concern 1) oxygen and 2) total pressure. An automatic pre-scheduled repressurization system is required to insure maximum probability of survival in the event of an accident. Supplemental features such as close surveillance and operations control are necessary to further insure against conditions hostile to man.

2.0 General Considerations

2.1 Oxygen Partial Pressure (Physiological) - The functional state is determined by relating: 1) alveolar oxygen partial pressure to atmosphere state, 2) arterial hemoglobin saturation to alveolar oxygen partial pressure, 3) tissue pO_2 to arterial hemoglobin saturation, and 4) functional state to tissue pO_2. It is satisfactory to utilize atmospheric oxygen partial pressure and general functional state for this purpose. Thus the human functional state = f (ambient pO_2).

One human restriction most concerns the sensitivity of the body, particularly the brain and heart, to oxygen deprivation; the body has limited oxygen reservoir and retention capability. In addition,

hypoxia is insidious. Oxidative processes sustain the metabolism of all tissues, and man lives a "hand to mouth" existance with respect to oxygen.

In the absence of oxygen, unconsciousness follows in a few seconds (as quickly as 8 to 10 seconds for rapid decompression) and death within minutes. The need for oxygen for viability and consciousness is continuous.

Lung ventilation is normally between 1/4 and 3/4 ft^3/min. The volume of inspired and expired gas is seldom equal because of the difference between oxygen consumed and CO_2 produced, and of water vapor exchanged. Water vapor is continuously evaporated in the lungs and respiratory passages, and being a function of temperature is normally about 0.9 psia in the alveoli. Nitrogen (and other inert gases) passes in and out of the lungs in equal quantities under conditions of steady state ambient pN_2 partial pressure. O_2 and CO_2 pass across the lung alveoli membrane at rates determined by partial pressure differences which are determined by the lung ventilation rate, blood flow, the ambient oxygen partial pressure, and other physiological characteristics.

The relationships of FO_2 (oxygen fraction), pCO_2, and RQ (respiratory quotient = pCO_2/pO_2) can be assumed constant for the purpose of developing design criteria. As indicated, functional state (ambient pO_2) and consequently, at some points in a repressurization rational, time-ambient pO_2 must be specified. The required minimum total pressure at various times must be considered, because together with ambient pO_2 recovery and combustion hazards, it establishes the design constraints on repressurization.

Fig. IX-1 shows max-min pO_2 and rate criteria which indicates a rapid recovery of total pressure and pO_2. The specification for an intermediate pO_2 level can be derived only if the oxygen fraction and the exact nature of the protective equipment failure can be confidently established. The oxygen fraction will depend greatly upon the possible thermal and combustion processes occuring during repressurization. Ideally 100% oxygen would be desired regardless of the type of failure, but a mixture of 50% nitrogen and 50% oxygen would be acceptable. It can not at this time be shown what the optimum oxygen fraction should be nor that it can be determined from physiological considerations only.

Fig. IX-1 also indicates that a discontinuous function of oxygen partial pressure (i.e., 2 isolated pO_2 time points) and total pressure are to be considered for repressurization design. The upper limit of 5 psia, indicated for any automatic pre-set pressurization schedule, does not

preclude continued uninterrupted pressurization beyong 5 psia, but only indicates that control beyond 5 psia should revert to the chamber control room and should be a function of a human operator having feedback from the chamber or airlock occupant. The diluent is assumed to be nitrogen. Unless a thermal control problem exists which requires the use of helium or other diluent gas, no other gas should be considered.

The selection of an intermediate pO_2-time point cannot be completely rationalized in detail at this stage, since in addition to unresolved conflicting systems considerations, it is a transient point.

As specified, it merely indicates the urgency for fast repressurization. The second criteria point specifies a minimum ambient chamber pO_2, at the oral-nasal region, resulting in a sea level equivalent air condition.

2.2 Oxidation Hazard (Physical-Chemical) - Inasmuch as oxygen is a vital element in all manned life support systems, repressurization of a "man-rated" chamber with an oxygen rich gas is a requirement. "Oxygen rating" of chamber equipment is therefore, synonymous with "man-rating" to insure that accidental combustion or detonation cannot occur.

This problem requires careful consideration of all materials utilized for either fabrication or operation (lubricants and diffusion pump oil) of the chamber, to insure that they are stable in the presence of oxygen rich atmospheres.

2.3 Thermal Hazard (Physiological) - Clothing is essentially an insulative covering for the body. In addition to fairly predictable thermal impedance, a pressure suit provides supplemental pressure for the body. A pressure suit designed for use external to a space vehicle will probably have a low α/ϵ ratio. A high heat capacity is also desirable for short duration "cold" or "shadow" exposure. The heat capacity and insulation characteristics would be very helpful in accommodating temperature fluctuations which might occur during emergency repressurization.

There is very little experience in short duration exposure to extreme and localized temperature conditions which might occur during repressurization, contact with cryogenic surfaces, or unprotected facial exposure to solar source. In suit design, consideration should be given to these conditions in addition to those existing in space and on the moon.

Damage depends on the temperature and duration of the heating or cooling. Experiments have shown that a flash-type thermal dose of

2K cal/cm^2 incident on tissue can produce a first degree burn, and in excess of 4.8K cal/cm^2 is required to produce a third degree burn. The effects of excessive cold upon the tissues result from extreme vaso-constriction, intracellular formation of ice crystals, and injury of small arteries, veins, and capillaries. A transient low temperature condition during repressurization should be assumed because of: 1) the difficulty in determining the time required for removing liquid nitrogen from the cryogenic panels and 2) the uncertainty in heat transfer to the cryogenic panels. A high heat gain condition should also be assumed, since either chamber, and particularly B, could be operated for tests requiring only roughing pumps. In this case, the temperature could rise greatly in the chamber upon repressurization, unless a high proportion of the repressurization gas is stored at high pressure, providing cooling on use. (Joule-Thomson effect)

Calculations indicate cooling to be in the order of 35°F below storage temperature for high pressure gas and a temperature rise of up to 250°F for atmospheric air.

Cryogenic surfaces may require guards to prevent inadvertent or even normal contact by personnel, since vision capability will be less than normal. Malfunctions must be assumed, also, which compromise the thermal properties of the "work" type pressure suits and of even the lunar suits during their development testing.

Recovery of temperature to within 35 to 100°F on critical access-ways within 5 minutes should be considered. Requirements listed below for the period of automatic repressurization are conservative even with a high heat transfer coefficient based upon the design time response of density and dynamic pressure. This is appropriate to limit additional compromise of personnel recovery.

2.4 Total Pressure - Another human design constraint concerns the development and/or transport of evolved gas within body tissues and the circulatory system upon lowering ambient pressure.

"Evaporative boiling" and "space ebullism" are terms used to describe the phenonmenon of vaporization and dissolution of body fluids. Expansion of entrapped gases in the lungs and gases normally found in the gastro-intestinal tract can also be distressing.

Diluent gas evolution is largely manageable by breathing 100% oxygen. Pressure, or pressure change, affects the amount of nitrogen dissolved in tissues and the circulatory system, but most nitrogen can be eliminated before ascending above 18,000 ft by breathing 100% oxygen for about

2 hours. In any case, unless a failure resulted in a final pressure equivalent to an altitude of about 63,000 ft or less, the effects of dysbarism are of less immediate concern than is tissue fluid "evaporative boiling" or "ebullism".

Ebullism is defined as the vaporization of body fluids at body temperature resulting from lowered ambient pressure. It may occur without formation of bubbles when ambient pressure is reduced slowly before reaching the vapor pressure of the liquid. Onset of hypoxia will occur in the event of slow ambient pressure fall even with 100% oxygen; on the other hand, loss of consciousness and then effects of ebullism would result with a rapid or explosive decompression.

Times required to re-establish oxygen partial pressure and ambient pressure to prevent irreversible effects of either phenomenon have not been determined. Time is critical and certain pressure levels are absolutely necessary. Repressurization to 1 psia must be attained in order to prevent ebullism, and to 5 psia to preclude dysbarism effects. Some oxygen partial pressure must be re-established in the tissues within seconds after decompression to prevent a latent period of unconsciousness; and to sea level air conditions for complete recovery.

The latter should be carried out as quickly as possible without producing perforation of the eardrums. Little difficulty is generally encountered in very rapid repressurization to 4 or 5 psia. In addition this level is satisfactory for minimizing oxidation hazards if a diluent gas is used, and reduces the thermal problem.

The effective ebullism pressure will vary slightly throughout the body because of temperature variation, varying differential pressure inward from the ambient or skin pressure, and physical-chemical factors such as dissociation functions of volatile solutes and colloidal effects. At higher pressures than 1 psia, evaporative and perspiration rates at a given body temperature will begin to increase. (This normally produces a beneficial effect upon body thermal control over that at sea level.) Surface water loss would probably account for the greater fraction of vapor formation, but moist integument parts such as the mouth and eyes, would also provide a copious source of vapor. This together with trapped gases already within the gastrointestinal track, could produce gastrointestinal injury. Sufficient vapor might form rapidly enough to seriously impair vision.

A considerable pressure gradient exists throughout the systemic circulatory system. The greatest pressure drop occurs across the arterioles, capillaries, and venules; venous return takes places at a very reduced pressure. Vaporization would thus begin most

vigorously at the entrance of the great veins to the heart and progress down through the tissue level. Results from hypoxia and the above phenomena would amount to cardiac vapor lock and circulatory arrest could occur well within 15 seconds.

The normal range of body temperature determines critical H_2O partial pressures and thus fixes the ambient pressure which must be provided to prevent evaporative boiling. Prevention, of course, is most effective if the application of pressure (pneumatic preferably) over the entire body occurs sufficiently quick to prevent the start of evaporative boiling. This dictates almost immediate development of about 1 psia pressure. Ten seconds is a practical time for achieving this goal considering equipment design problems and the physical/chemical phenomena.

All of the foregoing points are design guide points based on certain assumptions, which cannot be completely valid for all conceivable chamber and test conditions. For instance, the chamber oxygen partial pressure is less critical if the buddy system is assumed to be "effective" as a supplement to repressurization, since the pO_2 established in the chamber immediately after a pressure suit failure is critical only if the pressure suit helmet is opened before or during recovery and if the failure limits the umbilical or emergency oxygen supply of the subject.

Otherwise the chamber pO_2 is not immediately recovered inside the helmet anyway.

This condition does not mitigate against repressurization, but only supplements it under certain conditions. Rapid repressurization is mandatory for the recovery of a small total pressurization, and it is a necessary adjunct to the buddy system. Together they constitute a very potent recovery method for clothing and equipment failures in a hazardous space environment.

2.5 Surveillance - Subjects should be individually and visually monitored throughout the time they are under test. Direct observation is preferable, but may not be possible at all times. TV coverage and a safety observer in an air lock (herein referred to as man-lock) watching two subjects provide alternate and supplementary solutions. Direct viewing into the chamber may not be fully effective because of interference by necessary chamber components. However, at least one and preferably two windows should be provided for use by safety personnel in the man-lock. Ideally each window should allow

a field of view of the entire walkway. If impractical, close attention to voice communication and viability measurements can suffice for those test operations which may be partly out of view.

The light absorbing characteristics of the walls of the test chamber are not likely to provide visual stimuli normally useful in depth perception. It may be necessary to give individuals in the chamber and in the man-lock other visual stimuli to aid in depth perception.

Also, visual problems may be encountered in the normal use of pressure suit helmets such as restriction in field of view, distortion due to the visor shape, and loss of visual acuity because of fogging or methods used to eliminate fogging. Assistance may be provided by placing a pattern of regular markings on the floor, on guard rails of the walkways, on man-lock doors, other chamber areas, and on special equipment used in particular tests. As testing becomes more specific, these might be eliminated since under some simulation conditions, it may be desirable for a subject to have the illusion of standing alone in space.

TV coverage will probably indicate only gross movement, and should be considered as a supplement to voice communication from both the man locks and chamber. Together, voice and TV will provide the picture for those in the control room and should be provided in both the vehicle cabin and in the chamber.

Surveillance capability would not be complete without voice and voice back-up channels. Only visual information is more important, and even then a "buddy" would be dependent on voice communication for relay of his visual information. Back-up voice is provided in Mercury, and can be expected to be required in other manned space systems.

Individual viability measurements should be provided for each subject in the chamber, and should consist of not less than respiration and pulse. ECG and heart muscle vibrational energy offer greater diagnostic value but pose a greater implementation problem.

Pressure in the suit of each subject is a most critical environmental parameter. However, oxygen partial pressure could be required in addition to suit pressure in instances where the suit is connected to a processing system providing separate control of both total pressure and oxygen partial pressure. ECG would indicate hypoxia, but could well be supplemented by an indication of suit pO_2.

Loss of total pressure, and as a consequence pO_2 is so critical that it should serve as a signal for repressurization without assent or manual

action by the operator or medical monitor. The signal should also be confirmed automatically by comparison with back-up or related information. A combination of baroswitches and pressure transducers should be utilized to provide a reliable indication of pressure loss for automatic actuation. Repressurization should also be initiatable manually.

2.6 Operations Control - Human Factors design practices should be considered in the control room and operator workspace layouts, for console configurations, operator environment, maintenance capability and detailed requirements for controls and displays. In general, the control room design should provide operators with the capability of establishing and maintaining test conditions, and to return to nontest conditions in a controlled and predictable manner.

If a function is critical and likely to induce failure or place the test or support subjects and equipment in jeopardy, automatic control is desirable. The panel should present information consistent with the test mission. Sequential steps should follow from left to right and top to bottom, and simultaneous events in a vertical array along a horizontal time line. In cases where the operator is required to monitor a programmed sequence he should be provided with visual indications of progress and/or malfunction. Where no clear-cut sequence of operations determines the order of events, the panel layout should consist of functional groupings of displays and related controls. Where appropriate, sequential groupings may be employed within the functional groups of displays and controls. Related displays and controls should be placed in close proximity to one another with the displays located above the associated controls. Functional groupings should be outlined and the area may be appropriately color coded.

Displays and controls should be spatially organized wherever possible so that the relationship between functions is apparent to the operator. The display movement most appropriate for a control is one that is in the same direction as the control motion, (i.e., both clockwise or both vertical, etc). Multiple displays and controls can be visually checked for a go/no-go or null position if they are aligned in the same direction or the same relative direction.

Viewing angle should not be greater than 30-50 degress from the normal to the display or control. Labels should be close to the control or display within 3/4 inch preferably. Operations terms should be favored over engineering terms, and abbreviations should be avoided wherever possible.

Direct manual operation of certain essential valves may be necessary. Failure of all electrical power, both primary and back-up, should not jeopardize the chamber operation. Spring or pneumatic, or hydraulic actuation to a fail safe position upon electrical power failure should be considered. Inspection of and feedback from equipment and actuation methods and control devices should be provided wherever possible without removal of covers or guards to the extent necessary to check their operation routinely. Functions that are critical to chamber operation should provide remote indication of status.

Pressurized gloves and helmets will normally be used in the manlocks and chambers and their restrictions should be considered in the placement and design of controls and displays in those locations.

Individuals in the chamber and man lock should have controls available to allow operation of each lock and the chamber in those functions necessary to allow independent recovery to the outside. Rapid equalization of a man lock into the chamber should be considered. Normal decompression or repressurization would be amply met with a rate of 5 psi/min and controllable to hold position at any time.

Lighting and cryogenic surfaces may impose restrictions to movement in the simulator. These restrictions may be accommodated by specific test provisions. Cryogenic surfaces could be "fenced out" of contact; although test or work pressure suits could include appropriate material and insulation for protection, since the lunar and extra-vehicular suit will have to meet comparable thermal conditions.

Emergency repressurization must consider control of dynamic pressure and temperature as well as static pressure. Removal of the liquid nitrogen in the cryogenic pumping system upon automatic repressurization is desirable even though the subject (s) may be considered to be removed to a man lock immediately after 5 psia is reached and repressurization reverts to normal manual control. Also, particular access-ways and associated surfaces in the chamber could be warmed-up upon automatic repressurization to allow use of less restrictive clothing by rescue personnel.

Floodlights should be turned on before automatic repressurization is begun and the solar source reduced quickly by at least 50%. Together these lighting signals plus an audio signal through both communication channels should provide adequate warning of impending rapid repressurization.

Dynamic pressure must be limited during repressurization to prevent upsetting subjects. Air injected upward or downward over the subjects would be less upsetting than from the side. However, a vortex may result in either case and control should be provided to limit the dynamic pressure. Preliminary calculations indicate that the upper limit of impact pressure, assuming a very short warming time and air injected from below, should not exceed 15 lbs/ft^2. Experimental verification of these calculations will be necessary.

2.7 Work Capability - Man performs physical activities in a variety of ways. The manner in which he performs these activities is influenced by his body build, physiological functions, and psychomotor patterns. Various types of restrictive personal equipment will be used routinely in the chamber, as well as special personnel life support provisions on occasion. There will be components in the chamber which may further limit the subject's ability to help himself or his buddy and special test equipment which may limit visibility, accessibility and mobility within the chamber. Consideration should be given to these constraints to accomplish practical recovery capability, and to minimize the man rating equipment as contributors to accidents.

The general approach to this problem is to provide suitable (42 inches wide) walkways, guard rails and handholds, accessible man locks and good traction walk surfaces under all test conditions. There should be a minimum of elevation change and need for climbing. Personal life support equipment compatible with the biomedical capability of personnel in a one "g" field should be provided along with functional recovery equipment and emergency power provisions.

2.8 Buddy Safety System - To insure the safety of a man in the chamber during operation, the concept of utilizing a "buddy" for immediate first aid is considered necessary. The suited man may still be in a closed system in many types of failures even though the chamber is repressurized with an oxygen rich gas mixture. Consequently, repressurization may not necessarily produce a satisfactory environment around the man.

Each individual entering the chamber for a particular mission should, therefore, be accompanied by a second suited individual whose sole mission is to render first aid assistance in the event that the first person encounters difficulty or an accident. An oxygen mask/regulator should be provided for emergency use within the chamber for each occupant as well as a "garment bag" pressure suit and stretcher assembly.

In addition, there should be constant surveillance by at least one other suited individual in the nearest man lock to lend assistance during retrieval.

3.0 Concepts - Man rating of a space chamber should be based upon the following:

a. Man rating should be an integral part of the chamber design.

b. Exposure of personnel to simulated space environment for training, manned system development, etc., should be accomplished in such a manner as to instill the utmost confidence into the individual involved.

c. Surveillance of test personnel should be complete and environmental conditions should be controlled throughout, with control back-up and with manual/mechanical interrupt provided.

d. Human factors design practices should be applied to control room and operator work space layouts, console configurations, operator environment, maintenance capability, and controls and display layouts.

e. Recovery, retrieval and survival techniques of a highly reliable nature should be provided.

f. Test personnel should be able to effect their own recovery independent of assistance to the fullest extent possible.

4.0 Implementation - Evaluation of possible implementation methods entails consideration of human and equipment constraints insofar as they effect the detailed facility design. Prime items which should be considered in man rating a chamber are listed below:

4.1 Man Lock

a. Size should be sufficient to comfortably accommodate the total number of persons for which the environmental control system is designed or for the crew of the vehicle under test, plus two attendants. (minimum area - 15 ft^2/man).

b. At least one parallel lock unit should be available on each chamber at the lunar level. Such a unit would consist of two locks with a common wall and a two-way pressure door between them. This arrangement provides maximum surveillance flexibility and still affords two stage repressurization as does a standard series configuration.

c. Doors into chambers and to the atmosphere should be sufficiently large to permit passage by pressure suited men assisting an injured subject (recommended size - 4 ft by 7 ft).

d. Doors into chambers should be capable of being opened from either side by suited men; doors may swing into air locks.

e. Independent vacuum pumpdown to 10^{-3} mmHg in one-half hour should be possible and repressurization features independent from the chamber must be provided.

f. Umbilical provisions should be made for suited subjects; each umbilical connection should compose two dual lines for low pressure (3.5-5.0. psia.) 20 CFM gas circulation (1 1/2 inch pipe), a single duct line for 100 psia oxygen (1/2 inch pipe), and 12 channels of electrical circuits for bio-medical instrumentation and voice communications.

g. Provisions should be made for TV camera coverage and adequate internal lighting.

4.2 Accessibility

a. Provisions should be made for easy external access to all man locks.

b. Internal platforms and catwalks should be provided to allow easy and safe access inside the chamber with sufficient protection incorporated to prevent falls and inadvertent damage to suited subjects through either normal or accidental contact with cryogenic surfaces.

c. Appropriate internal catwalks should be provided at each man lock level to allow passage of two suited individuals and to allow removal of an injured subject by stretcher into the man lock.

4.3 Instrumentation and Control

a. Provisions should be made for voice communication and surveillance of important ecological conditions by a biomedical observer at a biomedical console in the control room for each suited man in the chamber or man locks.

b. TV viewing capability in the control room for all subjects in the chamber and manlocks should be provided.

c. Lighting with appropriate controls to satisfy both internal accessibility and TV viewing needs should be provided.

d. Provisions should be made for manual as well as automatic repressurization in the event of a serious accident in the chamber or man locks.

e. Sufficient information should be provided for the biomedical observer to permit monitoring and control of the environmental syetems and monitoring of the well being of the subjects.

f. Provisions should be made for continuous recording of all environmental and ecological data.

4.4 Environmental Control System - An environmental control system should be provided capable of controlling the environment of suited subjects with the ability to vary the following conditions through at least the following limits:

a. Total pressure between 3.5 and 5.0 psia.
b. Oxygen partial pressure between 3.5 and 5.0 psia.
c. Carbon dioxide partial pressure between 2 and 19 mmHg.
d. Relative humidity between 30 and 90%.
e. Inlet temperature between 50 and 80°F.
f. Flow rate between 10 and 120 CFM

All conditions should be monitored, controlled and recorded from the biomedical console.

4.5 Automatic Repressurization System - An automatic repressurization system should be provided which is capable of achieving an oxygen partial pressure and a total pressure in the chamber within the following schedule:

a. 50 mmHg (1.0 psia) in 12 seconds - total pressure
b. 85 mmHg (1.6 psia) in 30 seconds - oxygen partial pressure
c. 180 mmHg (3.5 psia in 180 seconds - oxygen partial pressure
d. 260 mmHg (5.0 psia) - total pressure (time not critical)
e. Maximum pressure rate should not exceed 0.2psi/sec
f. Automatic repressurization should not exceed 260 mmHg.

Manual repressurization from 260 mmHg to ambient should not exceed the maximum rate of 5 psi/min with complete control and "hold" capability provided through the range. Manual controls should be provided for actuation at the biomedical console. Automatic repressurization should be actuated only from signals emanating from critical suit conditions. Temperatures of incoming gas should meet the following schedule:

Temperature Range (^{o}F)	Elapsed Time (Minutes)
-30 to 200	2
15 to 150	5
35 to 100	10

REPRESSURIZATION CRITERIA

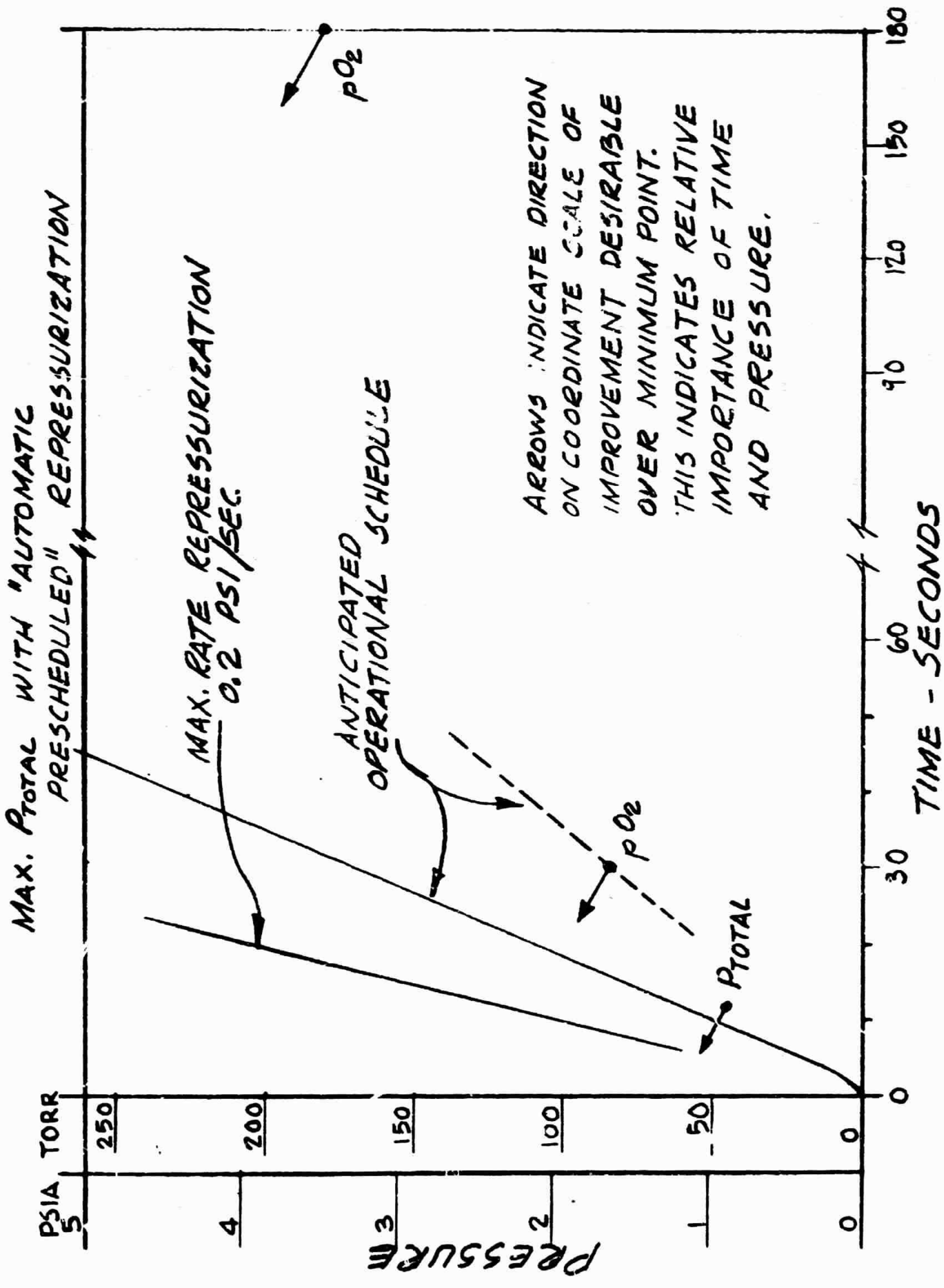


FIG. IX-1

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SECTION X
CONTROL AND INSTRUMENTATION

1.0 Basic Variants - Three basic modes of Process Control have been investigated and evaluated; namely, a) local, b) central, and c) central-automatic. These three concepts are represented in block diagram form in Fig. X-1.

a) Local Control Mode - In this approach, the process instrument control panels are all local (field mounted) and are located as close as possible to the primary and final control elements. The controller primary sensing elements are generally within each controller case thus reducing the need for local transmitters. The local control panels are grouped into control board areas in order to reduce the number of operating areas and operators required. The Control Evaluation Chart, Fig. X-2, compares each control mode against several criteria. The local control mode is not recommended because of poor communication and program control and the large number of personnel required for operation.

b) Central Control Mode - In this approach, the process instrument control panels are located in one central control room and include all primary controllers necessary for proper facility operation. Local panels are used to supplement their controlroom counterpart and include instrumentation not essential to primary control. The local panels are located as close as feasible to the process involved and transmitters are generally used between the local panels and the main control room panel. The control room panels are oriented to represent actual process flow through the facility or with respect to the actual location of facility systems.

The control evaluation chart indicates that communication and program control is improved and the number of personnel required for operation is minimum. This concept would be suitable.

c) Central Automatic Control Mode - In this approach, the process control concept is indentical to that of the central control mode with the exception that additional automatic control circuitry provides for remote set of controller set points with cascade and program functions from a facility computer.

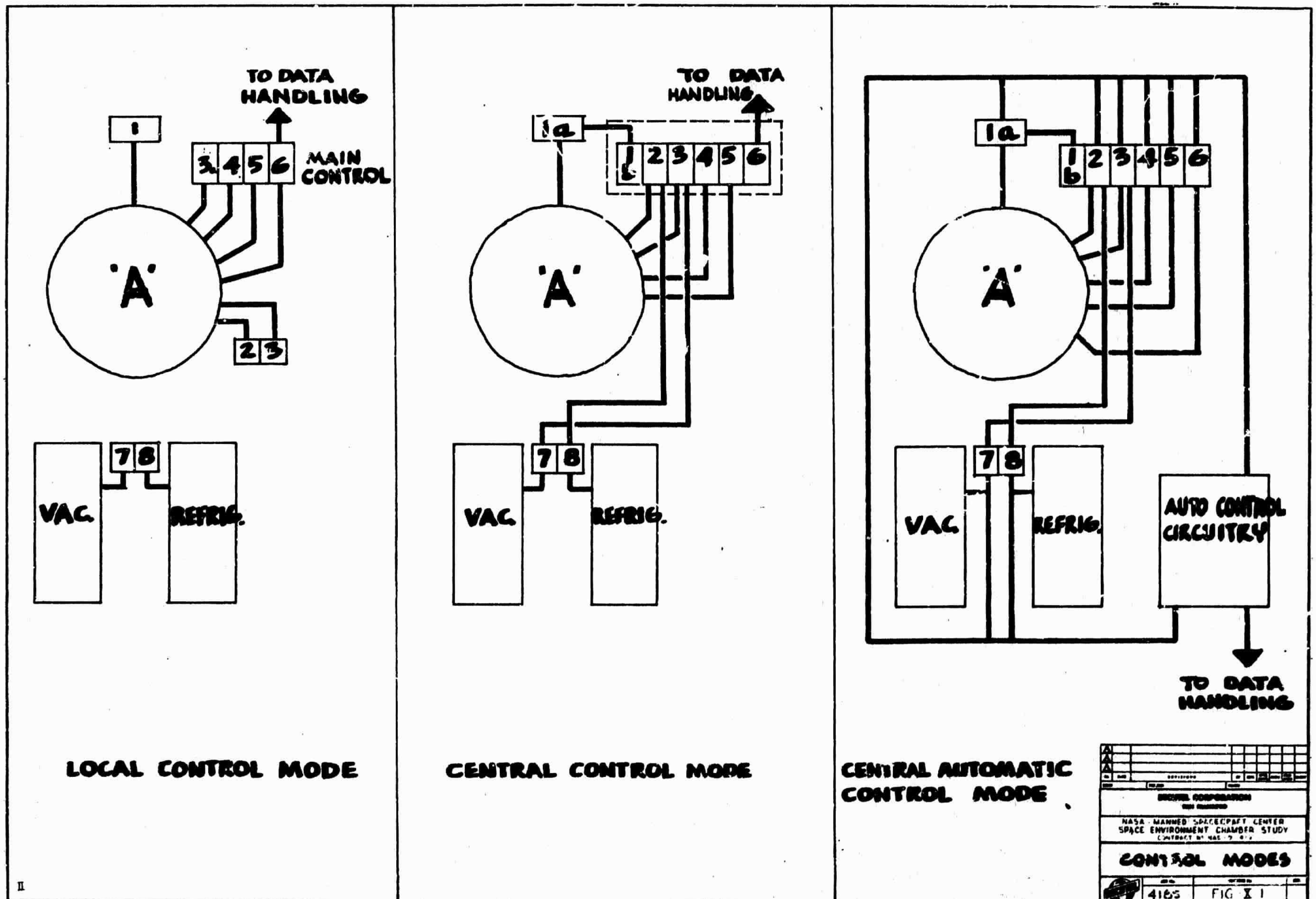
The control evaluation chart indicates that the cost is increased but no further reduction in the number of operators is anticipated. This system would be desirable for the facility because of its high speed of

response and because on line control functions might be time shared on the data handling computer.

2.0 Panel Requirements - The total lineal footage of control panel is 136 ft for all control modes. The basic difference between the local and central mode is the relocation of local panels to the main control room and the additional transmitters required.

3.0 Limited Central Control - A modification of the central control mode concept employing the same components was also studied. This concept (Fig. X-3) is based on the requirement that no personnel need attend the local boards during normal operation, including startup and shutdown, except for the local board of the solar simulator where a maintenance crew must be on hand for replacement of lamps. Only essential primary control functions are located in the control room. Information essential to cognizance of test conditions and alarm panel for abnormal conditions are displayed in the control room. Upgrading of this system to the central automatic mode can be accomplished with a minimum expense.

4.0 Recommendation - The limited central control system is recommended for this facility and a conceptual design is described in Volume III.


TO DATA HANDLING
MAIN CONTROL
"A"
VAC.
REFRIG.
LOCAL CONTROL MODE
TO DATA HANDLING
"A"
VAC.
REFRIG.
CENTRAL CONTROL MODE
"A"
VAC.
REFRIG.
AUTO CONTROL CIRCUITRY
TO DATA HANDLING
CENTRAL AUTOMATIC CONTROL MODE
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTROL MODES
4165
FIG XI

II

CONTROL EVALUATION CHART

CONTROL MODES	PANEL LENGTH LINEAL FT. (ALL MODES)	OPERATORS / SHIFT LOCAL	CENTRAL	AUTOMATIC
1 SOLAR SIMULATOR	16	3	2 LOCAL	2 LOCAL
2 CRYOGENIC	30	2		
3 DIFFUSION & BACKING	23	2		
4 SAFETY SHUT DOWN	12	1	3	3
5 VIDEO	12	1		
6 POSITION & VIBRATION	14	1		
7 VACUUM PLANT	15	3	3	3
8 REFRIGERATION PLANT	14			
TOTAL PANEL	107			
PERSONNEL		13	8	8

CRITERIA	LOCAL.	CENTRAL	AUTOMATIC
COMMUNICATION	P	G	E
PROGRAM CONTROL	P	G	E
EFFICIENCY	P	G	E
MAINTENANCE	P	G	G
RELIABILITY	A	G	E
STABILITY	E	E	E
PRECISION	E	E	E
COST	G	A	P

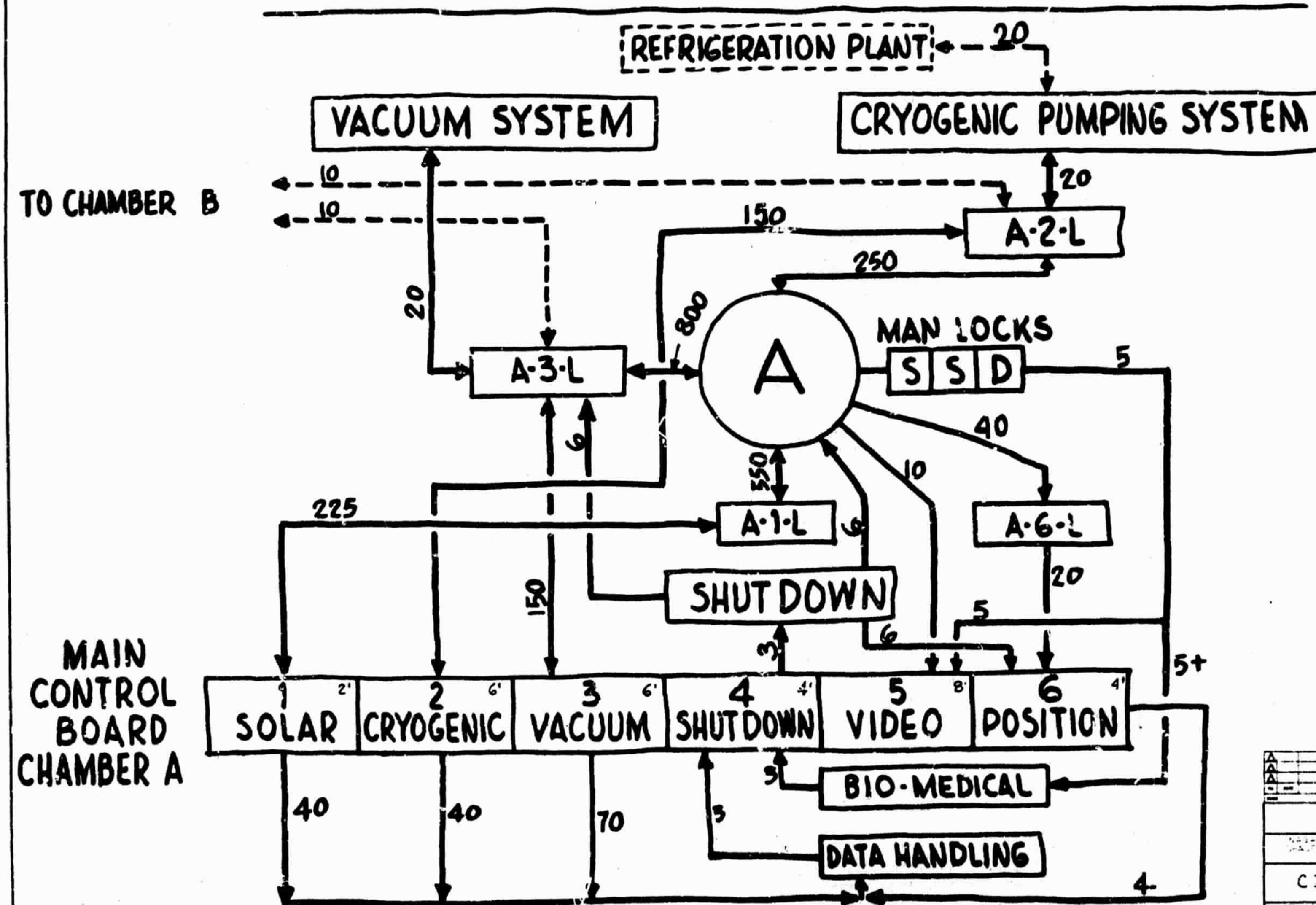
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

CONTROL EVALUATION CHART

4186 FIG X-2

11

PRIMARY CONTROL BLOCK DIAGRAM



BECHTEL CORPORATION

CID SYSTEM

4185 FIG. X-3

II

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SECTION XI
DATA HANDLING

1.0 Test Requirements

1.1 General Requirements - The data handling system includes all that equipment necessary to sense, transmit, process, record, display, and react to the vehicle, facility, and ecological performance parameters which should be evaluated during a vehicle system environmental test program. There are seven criteria which govern the selection of a design for a conceptional approach to such a system. They are test conformance, safety, central cognizance, optimum data form, data correlation, flexibility, and expansion capability.

Test Conformance - The system should insure that the tests are performed in conformance with the prescribed test limits and sequences.

Safety - It should provide complete safety to men in the chamber , to the facility, and to the system under test.

Central Cognizance - It should be designed so that the test conductor maintains complete cognizance of the operation of the facility and test system.

Optimum Data Form - It should provide test data in a form permitting optimum utilization. Cognizant performance information (not data) is presented on line, and the evaluation data is formatted for optimum recovery.

Data Correlation - It should permit full correlation between facility data and test system data.

Flexibility - It should permit maximum test flexibility.

Expansion Capability - The data handling system should permit maximum expansion at as low a price per variable measured as possible.

1.2 Specific Chamber Requirements - There are four areas from which data will be derived. These are the vehicle systems, the vehicle structure, the facility, and the ecological factors. The requirements outlined herein are a compilation of the test point requirements provided by MSC and estimated requirements derived from experience in testing of similar systems. The requirements for Chamber A and B are similar and the following discussion is applicable to each.

1.2.1 <u>Vehicle Control</u> - Vehicle systems and subsystem control and monitoring equipment should be provided by the vehicle development program. It must be designed to satisfy the control and monitoring problem associated with that particular program, but should also be compatible with the central data handling facility. The data handling system should have a twofold requirement; it should provide cabling and penetration for the routing of vehicle power, control and monitoring signals between the control room and the vehicle, and it should monitor, record, and, for purposes of test coordination and safety, provide programming or feedback control signals to the vehicle control equipment.

1.2.1.1 <u>Chamber Penetrations</u> - It will be necessary to provide wires to the vehicle carrying ground control and power signals, simulated second stage input signals, vehicle performance and monitoring test points and special input stimuli. A total of 256 input wires should be provided. A tentative breakdown of the usage of these wires is:

4	-	# 10 Prime power	umbilical
48	-	# 16 Vehicle control	
100	-	# 22 Twisted pair shielded (50pr) vehicle performance monitors	
100	-	# 22S Vehicle performance monitors	
4	-	Coaxial RG9 for RF signals	

These wires should be brought from vehicle test connections via a set of cables provided with the vehicle to a set of connectors on a panel on the rotating platform. The facility wiring should then accomplish routing back to the control room.

1.2.1.2 <u>Vehicle Control and Monitoring</u> - A typical vehicle system may include a number of subsystems including:

Power, Control and Distribution
Attitude Control
Guidance
Telemetry, Tracking, and Command
Propulsion
Pneumatics
Special Communications
Life Support
Recovery
Special Sensory or Experimental

The types of tests to be performed on each will include both static and dynamic tests, each of which will present a different data handling problem. The static tests will be performed during the majority of the time and will involve steady state readings on the stabilized vehicle. Sampling rates may be fairly slow and a relatively large number of points will be involved. During dynamic tests a vehicle subsystem will be stimulated with a dynamic input and its response characteristics measured. This test will involve high sampling rates and relatively few numbers of points. The data from these tests, because of the diversity of the subsystems, will include measurements of ac and dc voltage and current, audio to SHF frequencies, time intervals, rf power, logical operations and events, transfer characteristics or phase plane plots for control systems, human reaction characteristics, and other specialized measurements. The data handling system should have the capability of making dc analog measurements, digital measurements, and time interval measurements. Conversion equipment to convert vehicle data signals into these forms should be provided by the vehicle programs until sufficient funds and experience are gained to design and procure a universal data system. The data handling system should also permit rapid evaluation and reaction to vehicle data and it should permit flexible, accurate test programming of dynamic tests.

One special requirement is the area of telemetry data. The telemetry ground station and the data handling system should be integrated to permit correlation and/or complementing of hard wire and telemetered data.

1.2.2 Vehicle Instrumentation

Thermocouples - Monitoring and recording capacity for 500 thermocouples for Chamber A, and 500 for Chamber B should be provided. Reference junctions capable of handling chromel alumel, iron, constantan, or copper should be provided.

High Level - This group will include measurements of vehicle internal pressure, pneumatic pressure, thermistors, gas content, viability sensors, shutter or position indicators, etc., all in the 0-5 vdc range. These sensor leads should also be routed from the vehicle through the rotating table and through the bottom of the chamber. Sensor ≠ 5 vdc primary power should be provided as necessary. A total of 1,000 wires should be provided. Twisting and shielding requirements are defined later. Recording accuracy should be better than 1%.

1.2.3 Ecological Measurements

1.2.3.1 Subjects - Each man should be instrumented for basic physiological measurements as listed hereafter. For each subject, a section of a biomedical monitor panel should be used to display and record subject data. A magnetic tape recorder should record all

parameters as analog data throughout the test. Insofar as possible, automatic measurement and sampling should be used to verify viability.

a. Blood Pressure-A systolic measurement should be made by use of an occluding arm or finger cuff. Analog voltage should be scaled and displayed on a small strip chart. Data verifying operation of the automatic pressurizing and regulating system should also be displayed. An alternate method of instrumentation will use an indenting probe in the event that these become available. Accuracy shall be determined later.

b. Body Temperature - Three thermistors would be mounted in the subject's armpits. A digital display of the current value (5 minute intervals) should be available and a new value could be read and displayed upon request. Accuracy $\pm$ 0.3°F.

c. Electro-Cardiogram - Skin electrodes on the subject and amplifiers mounted within the space vehicle would transmit ECG data via coaxial cable to the medical display panel. Three (3) small oscilloscopes should be mounted in the panel to permit constant monitoring of ECG.

d. Respiration - A chest band transducer would be used to detect respiration characteristics. The output analog voltage should be displayed and recorded on a small strip chart which should be scaled to display depth and rate.

e. Subject Environment-Cabin - As a part of the vehicle instrumentation, the following measurements should be taken and displayed at the bio-medical panel:

1. Cabin Total Pressure - A barometric potentiometer should be utilized and data will be recorded for system performance evaluation. The information should also be utilized to initiate corrective action (cabin repressurization followed by chamber respressurization) in the event of a cabin loss of seal.

2. O_2, CO_2 Concentration - A mass spectrometer should be utilized tomeasure partial pressures of O_2 and CO_2. Vehicle instrumentation lines should be utilized.

3. Oxygen Reservoir Pressure, Flow - A potentiometric pressure transducer and a vane/turbine transducer should be used. Vehicle instrumentation lines should be used.

4. Cabin Humidity - An automatic wet and dry bulb thermometer system should be utilized. Vehicle instrumentation lines should be utilized.

5. Miscellaneous Life Support Measurements - As required, the following measurements can be instrumented and optionally displayed:

CO_2 Absorption Equipment Status
Cabin Air Circulation
Radiation Level
Acoustic Noise
Cabin Temperature

1.2.3.2 Pressure Suits

a. Baroswitches - Each pressure suit should have mounted within it 3 baroswitches which will activate at a pressure of less than 4 psia $\pm$ 0.2 psia, in order that damage to a suit can be rapidly assessed.

b. Baroresistor - A pressure transducer should be mounted in each suit to permit monitoring of the suit pressure for ecological evaluation and for safety purposes. Range should be 0-15 psia.

c. O_2 Demand - A turbine flow indicator should be mounted in each suit O_2 feed line to permit ecological data evaluation and to provide a safety indicator.

d. ECG - Electrodes and an amplifier should be supplied in each suit to permit monitoring of subject heart activity The ECG display for the three prime subjects should be monitroed. The ECG signals for other personnel should be recorded on a tape recorder and should share one display scope, which may be switched by the biomedical panel operator.

e. Voice Link - A closed voice loop should link all six suits, the test director, the vehicle cabin, the biomedical panel, and the airlocks. The loop should be recorded on one track of the biomedical tape recorder.

1.2.4 Facility Control and Monitoring - In order to completely evaluate vehicle performance and to permit the test conductor to maintain cognizance over the test operation, it is necessary to measure certain facility parameters and to provide control signals to the facility. These areas are:

a. Chamber Pressure - The chamber pressure transducer outputs should be used, along with status signals from the roughing, diffusion, and cryo-pumping systems to verify chamber suitability for test and for correlation with vehicle pressure sensors. The Chamber pressures should also be used in a decision circuit as a criteria for automatic repressurization initiation.

b. Solar Simulation - It will be necessary to record solar simulator intensity and display status. It is estimated that a maximum of 10 sensor leads will be necessary for intensity monitoring. Three digital points should be provided for status monitoring.

c. Turntable Control and Monitoring - In conjunction with thermal balance tests, it is necessary to control and monitor the table operation. A total of 5 digital points and 16 analog points should be provided for control and 7 analog points should be provided for monitoring. Programming control of the table should include an automatic mode for prolonged thermal balance tests in which it is desirable to investigate various positions and rates.

d. Repressurization - Provision should be made for automatic or manual repressurization based on evaluation of ecological and environmental parameters. Automatic control should be initiated by central control. If insufficient criteria are available for automatic repressurization, then a warning indication should be turned on at the bio-medical monitoring station, alerting the operator to make a decision to repressurize if physiological data warrants.

e. Airlock Monitors - The status and environmental conditions of the airlocks should be monitored and displayed for the test conductor. Five analog and 5 digital signals will be required for monitoring of each airlock.

f. Pressure Suit Electrical Outlets - A number of electrical receptacles should be located in the airlocks and in the chamber to route space suit measurements and communications circuits to the biomedical or test conductor monitoring equipment.

g. <u>Closed Circuit TV</u> - Jacks for a television camera should be located in the airlocks, in the chamber, and in the vehicle as necessary for monitoring test activity.

h. <u>Cryopanel Monitors</u> - Sufficient temperature sensors will be employed to permit temperature monitoring of the cryopanels. One point per panel will be allocated for monitoring.

1.3 <u>Sampling Rates</u> - The sampling rates for recording data will very depending on how critical the data are and on the type of test being run. For purposes of the design study five different levels of sampling rates should be considered. There are approximately 1,000 data points for both Chamber A and B. Estimated sampling rates and distribution are as follows:

Level	No. Points	Rate
1	820	1/20 spm
2	100	1/5 spm
3	50	1 spm
4	20	4 spm
5	5	12 spm

From the foregoing table a large majority of points will be slowly varying and will be used only for evaluation data. These should be sampled at a rate of once every twenty minutes. A small number of points are highly critical and should be sampled every five seconds and compared to limits to detect dangerous trends or out-of-limit conditions. It is assumed that for most tests it will not be necessary to record all of the readings taken at the high sampling rates. Based on the above table the total number of points that must be sampled in an hour for either chamber is 15,060 points, or a total of 30,120 points for the combined chambers.

1.4 Test Point Synopsis - Chamber A

		No. of Measurement Points	Control Points	Penetration Points	Sampling Rate (ea. pt.)	Display Points	Range	Remarks
I	Vehicle Instrumentation							
	a. High Level	200	—	1000	12, 4, 1, 1/5 & 1/20 spm		0-5 vdc	Pressure, Position, Temp. etc.
	b. Low Level	300	—	600	1/5, 1/20 spm			Thermocouples-Chromel alumel, or copper constanta
II	Vehicle Monitoring							
	a. Analog Monitors or Control	300		4 # 10 48 # 16	12, 4, 1, 1/5 spm		0-250 vdc	Central monitoring of vehicle functions - current, voltages. Analog actuation signals for programming. Monitoring of events, logic levels, digital decom output of TLM, etc. Central programming of voltage, events, and displays.
	b. Digital Monitoring Pt.	208		100 # 22 pts 100 # 22 s				
	c. Digital Control Pt.		360	4 RG 9				
III	Ecological Measurements							
	a. Prime Subjects							
	Blood Pressure	3			4 spm	3	40-200 mmHg	
	Body Temperature	9			1 spm	3	80-115° F	
	ECG	3		cont	cont	3	Pulse	Oscilloscope Display
	Respiration	3			cont	3	0-60 c/m, 0-50 cc/c	
	b. Cabin Environment							
	Cabin Total Pressure	1			1 spm		2-15 psia	
	O_2, CO_2 Partial Pressure	2			1/5 spm		150-350 mmO_2, 0-20 mmCO_2	
	O_2 Reservoir Pressure	1			1/5 spm		0-3000 psia	
	O_2 Flow	1			1 spm		0-12 cuft/min	
	Humidity	1						

Test Point Synopsis - Chamber A (Cont 'd)

		No. of Measurement Points	Control Points	Penetration Points	Sampling Rate (ea. pt.)	Display Points	Range	Remarks
III	Ecological Movements (cont'd)							
	c. Pressure Suits (6)							
	Baroswitches	18(d)			On demand		4 psia (switch)	Use as repressurization criteria
	Baroresistor	6			1 spm		0-15 psia	
	O_2 Demand	6			1 spm	0	0-4 cu ft/min	
	ECG (3 incl. in III a)	3			cont			
	Voice Link	6			---			
IV	Facility							
	a. Platform Positioning							
	Drive		21	30				
	Monitor	7			Variable	1 analog 5 digital	$0 \pm 180^\circ$	
	b. Vacuum							
	Monitor	4		12	1 spm	1 analog	1×10^{-6} - 7.5×10^2 mm Hg	
	Repressurization		1					
	c. Solar Simulation							
	Status	3 (d)			1/5 spm			
	Intensity	10		20	1 spm	1 analog	0 - 140 w/cm^2	
	d. Facility Status	40 (d)						
	e. Cryo Temperature	100			1/5 spm		50 - 200°K	
	TOTAL ANALOG POINTS	960	322					
	DIGITAL POINTS	274	360					

1.4 Test Point Synopsis - Chamber [illegible]

	Vehicle Instrumentation	No. of Measurement Points	Control Points	Penetration Points	Sampling Rate (ea. pt.)	Display Points	Range	Remarks
I								
	a. High Level	150	---	750	12, 4, 1, 1/5 & 1/20 spm		0-5 vdc	Pressure, Position, Temp. etc.
	b. Low Level	500	---	1000	1/5, 1/20 spm			Thermocouples-Chromel alumel, or copper constanta
II	**Vehicle Monitoring**							
	a. Analog Monitors or Control	300		4 # 10	12, 4, 1, 1/5 spm		0-250 vdc	Central monitoring of vehicle functions - current, voltages. Analog actuation signals for programming. Monitoring of events, logic levels, digital decom output of TLM, etc. Central programming of voltage, events, and displays.
				48 # 16				
	b. Digital Monitoring Pt.	208		100 # 22 pts				
				100 # 22 s				
	c. Digital Control Pt.		360	4 RG 9				
III	**Ecological Measurements**							
	a. Prime Subjects							
	Blood Pressure	3			4 spm	3	40-200 mmHg	
	Body Temperature	9			1 spm	3	80-115° F	
	ECG	3		cont	cont	3	Pulse	Oscilloscope Display
	Respiration	3			cont	3	0-60 c/m, 0-50 cc/c	
	b. Cabin Environment							
	Cabin Total Pressure	1			1 spm		2-15 psia	
	O_2, CO_2 Partial Pressure	2			1/5 spm		150-350 mmO_2, 0-20 mmCO_2	
	O_2 Reservoir Pressure	1			1/5 spm		0-3000 psia	
	O_2 Flow	1			1 spm		0-12 cu ft/min	
	Humidity	1						

Test Point Synopsis - Chamber B (Cont'd)

	No. of Measurement Points	Control Points	Penetration Points	Sampling Rate (ea. pt.)	Display Points	Range	Remarks
III Ecological Movements (cont'd)							
c. Pressure Suits							
Baroswitches	18(d)			On demand		4 psia (switch)	Use as repressurization criteria
Baroresistor	6			1 spm		0-15 psia	
O_2 Demand	6			1 spm	0	0-4 cu ft/min	
ECG (3 incl. in III a)	3			cont			
Thermistor	9			1 spm	3		Body Temperature
Voice Link	6			---			
IV Facility							
a. Platform Positioning							
Drive		21	30				
Monitor	7			Variable	1 analog 5 digital	$0 \pm 180^\circ$	
b. Vacuum							
Monitor	4		12	1 spm	1 analog	1×10^{-6}-7.5×10^{2} mm Hg	
Repressurization		1					
c. Solar Simulation							
Status	3 (d)			1/5 spm			
Intensity	10		20	1 spm	1 analog	0 - 140 w/cm^2	
d. Facility Status	40 (d)						
e. Cryo Temperature	100			1/5 spm		50 - 200°K	
TOTAL ANALOG POINTS	960	322					
DIGITAL POINTS	274	360					

2.0 Design Approaches

2.1 Facility Wiring - As a part of the basic facility cost, a complete set of penetration junction boxes and cables should be provided to route test points from the vehicle within the chamber to the associated control equipment in the control room. The facility wiring should be designed to permit maximum flexibility for making changes to the test configuration.

2.1.1 Penetrations - Penetrations through the chamber wall should be made by either potted cables or by penetration plates depending on costs and leakage rates. Enough penetrations should be provided to take care of the number of test points enumerated previously. Blank ports should be installed in the chamber wall to take care of additional future expansions.

2.1.2 Rotating Table Shaft Cables (Chamber A, Only) In Chamber A, a set of cables should be provided from the chamber penetration to a connector plate mounted on the rotating table. These cables should be designed to permit plus or minus 180 degrees flexing to take care of the table rotation.

2.1.3 Man-Rating Harness - Additional penetrations in cable harnesses should be provided for air locks and chamber umbilical connection points. A total of 30 such points will be necessary for the two chambers.

2.2 Data Handling - Three basic types of systems were considered for the data handling equipment. They were: a manual recording system, a semi-automatic data logger system, and a computer controlled system.

a. Manual Recording - In this approach, the test and data collection would be under full manual control. All quick-look data evaluation, decision making, and programming would be accomplished by the test operators. Test data would be transferred from analog records to punched cards for data processing.

b. Data Loggers - For this approach a large tape or patch board programmed data logger would be provided. Data would be taken automatically. The equipment would have a limited capability for comparing data to pre-set limits and for printing out alarm indications. Control, decision-making, reaction to limit alarms, and test programming would all be accomplished manually.

c. Computer Controlled Approach - In this approach, the test would be under computer control. Quick-look data evaluation, decision-making, reaction to alarm and corrective action initiation, and test programming would all be accomplished automatically. The test director would have capability for modification of sequences or limits during tests.

3.0 Economic Considerations - Due to the funding limitations, an approach must be taken which provides maximum data handling capability at the smallest initial capital expenditure. In pursuance of this policy, an entire data handling system is recommended for design, but only certain items will be included in the facility costing. Only those items which must be installed or fabricated as part of the chamber installation should be provided as facility items. The rest of the data handling system costs might be deferred to program funds or to facility operating funds. Some equipment would be purchased as an adjunct on vehicle program funds and some equipment can be leased as part of the facility operating costs (and perhaps charged to the vehicle program). As an example, all data scanning and recording equipment has been deleted from facility costs. This equipment can readily be leased on a lease purchase arrangement.

4.0 Recommendation

4.1 Design Approach Comparison and Evaluation - Selection of the optimum design is based on an evaluation using the seven design criteria listed below:

Test Conformance
Safety
Central Cognizance
Optimum Data Form
Flexibility
Data Correlation
Expansion Capability

Conformance to Test Limits - In order to achieve test conformance a manual system requires skilled, well-trained personnel in sufficient numbers to permit monitoring of all cogent data points and to take care of any exigencies that arise. The data logging system requires skilled personnel, although not as many as the manual system since data taking and comparison to limits are accomplished automatically. In the computer controlled approach the test is pre-programmed and conformance is automatically accomplished with a minimum number of operators.

Safety - The manual recording system must be considered unfeasible from the safety aspect. Detection and response to dangerous conditions are not sufficiently fast to insure test safety.

With automatic limit detection, the data logger system requires manual reaction to alarmed conditions; dangerous situations are detected automatically, but reaction to these situations depends on manual decision-making and action.

A limited number of critical items could be assigned to automatic monitoring and action to improve the speed and safety.

In the computer-controlled approach reaction to out-of-limits conditions and to dangerous trends is detected and corrective action initiated automatically. Reaction speeds in the order of 100 milliseconds are possible.

Central Cognizance - The manual and data logging systems both entail local control of the test. The computer permits central control.

Data Form - The manual recording system is again not feasible. Data handling of the number of points requiring analysis are beyond capability of human operators. The data logging system can provide adequate data formatting: output tapes can be handled directly by an IBM 1401 or 7090 computer without need for manual transfers to punched cards or tapes. One possible drawback is that telemetry data are recorded on a separate tape and must be integrated by a subsequent data handling installation into a correlated format. The computer is capable of providing a single, integrated, magnetic tape output, which contains hard wire data, telemetry data, and clock reference.

Facility-Test Correlation - The manual recording system would require subsequent data handling for data correlation. Manual data analysis and transfer to punched cards for computer entry would require approximately two days before the correlation could be achieved.

Since the output of a data logger is an IBM compatible tape, correlation of facility and test vehicle data could be accomplished within two to four hours with that equipment. For a computer based system, the important facility-test vehicle correlation would be accomplished on line. The remainder of the necessary correlation could be accomplished within an hour.

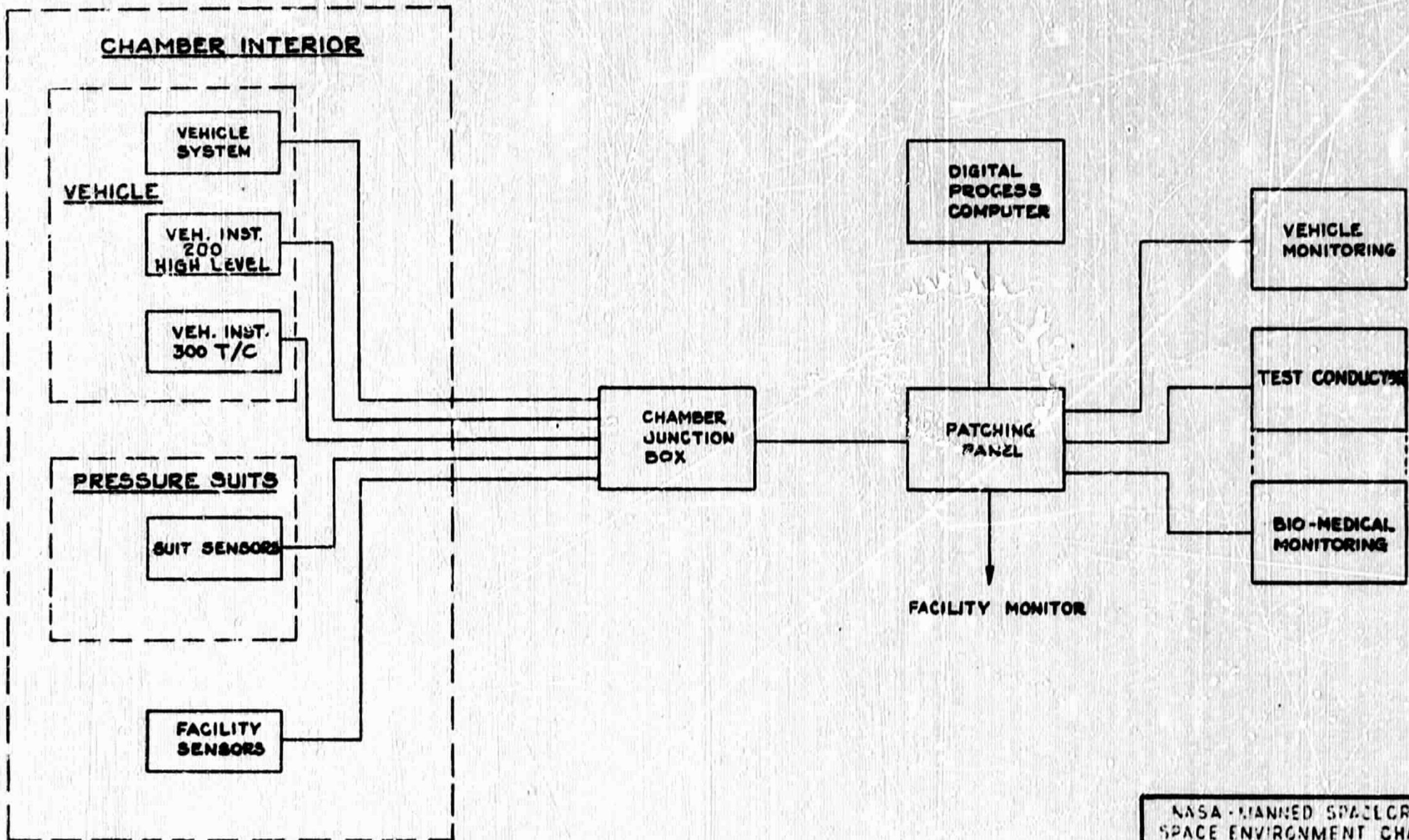
Flexibility - Flexibility for all three systems can be achieved by the design and installation of the universal patch board system which is contemplated as a part of the facility. The computer would permit an additional degree of flexibility in that programming changes may be made to the stored program during test.

Expansion Capability - The manual recording system has a severe limitation imposed by the sheer bulk of data to be taken. After a certain point it is not possible to provide sufficient operators and recording equipment to obtain a coherent record of the test.

The data logger is limited by recording speed (nominally, two to four points per second) and by the maximum amount of scanning equipment which can be incorporated in the logger.

Expansion of a computer system can be accomplished relatively cheaply within the capacity of the scanner-distributor. A nominal scanner would permit scanning of up to 3000 single-ended points, at speeds up to 175 points per second. Beyond this it is possible to add additional scanners to expand the system to 12000 points.

4.2 Recommended System - On the basis of the above evaluation and in the interest of minimum initial capital expenditure, it is recommended that the system to be designed and fabricated consist of facility wiring equipment, including chamber penetrations, chamber junction boxes, an extensive patching panel in the control room, and all necessary cables to interconnect these units. It is recommended that a digital process computer be leased as the data handling equipment. A full description and tentative specifications of the recommended system are included in Volume III, Part B, Section VIII of this report.



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CONTRACT NO NAS 9-419

ELEMENTS - DATA HANDLING

BECHTEL CORPORATION — POWER AND INDUSTRIAL DIVISION

JOB No 4185

DWG NO FIG. XI-1

SECTION XII
FOUNDATIONS

1.0 Site Information - The building site is approximately level and at elevation /20 above tidal datum. Soils engineering reports which were made for adjacent building sites were used as a basis for foundation studies. The soil stratification is generalized in those reports by the following layer descriptions.

Stratum	DEPTH (Ft) From	To	Description
I	0	2	Firm gray silty clay, organic
II	2	12	Stiff gray and tan sandy clay
III	12	27	Very stiff tan and light gray clay
IV	27	58	Very stiff tan and light gray sandy and silty clay
V	58	70	Dense, tan and light gray clayey sand, with sandstone seams and lenses
VI	70	88	Dense tan fine sand, with shell fragments
VII	88	(100)	Very stiff tan and light gray clay

Ground water level on the date the borings were made was about elevation / 15.5 or about four ft below the surface. Near surface soils are relatively impervious and no special dewatering was anticipated for shallow excavations.

2.0 Alternate Foundations

2.1 Spread Footings and Drilled-and-Underreamed Footings - The soils engineering reports indicated that spread footings or drilled-and-underreamed footings can carry up to 2 tons per square foot of bearing area on the clay if considerable settlement can be tolerated. Reduced bearing pressures would reduce the calculated settlements proportionately.

2.2 Piles - The soils reports provided curves for allowable compression and tension capacity of driven piles. The values at maximum penetration were as follows:

Type	Pile Capacity (Tons) Compression	Tension
16 inch square, precast	120	100
16 inch diameter, steel	115	62
10-3/8 inch tip, step-taper	80	48

2.3 Evaluation - For conceptual design, it was determined that lightweight buildings could be supported by drilled-and-underreamed caisson footings since the dead load bearing pressure could be made light enough to keep long term settlements nominal.

For heavy loads such as those imposed by the 120 ft high Chamber Building, it was apparent that spread footings or drilled caissons were not practical and would at best suffer more settlement than was considered acceptable.

Piles for the support of heavily loaded columns, chamber foundations or heavy equipment have advantages from the standpoint of economy, settlements, construction schedule and capacity for uplift. For the support of lightweight buildings, however, piles are uneconomical since the minimum piling plan which is capable of carrying eccentricities due to loading or pile driving would result in inefficient use of the pile capacities.

2.4 Recommendations

a. Chamber Building - This high bay structure is subject to very high wind loads which result in maximum net uplifts of 135 tons per column. Interior columns have dead plus live loads as high as 250 tons. This magnitude of loading and the desirability of eliminating settlements in this complex facility make pile foundations particularly suitable for this structure.

b. Chamber A Foundation - The chamber foundation is pit approximately 90 ft in diameter and some 25 ft below the water table as shown on Fig. XII-1, Scheme II. This condition imposes a large byoyant force on the foundation. The complex equipment connected to the chamber is intimately tied in with the building which surrounds it. These conditions lead to the obvious conclusion that the Chamber A foundation should be pile supported to eliminate any possibility of differential deflection between the chamber and the building and to conveniently carry the hydrostatic uplift pressure on the bottom of the pit without large bending moments and large deflections in the bottom slab.

c. Chamber B Foundation - The Chamber B foundation is a smaller shallower pit similar to the Chamber A foundation in all other respects. For the same reasons given for Chamber A foundation, it is concluded that the Chamber B foundation should be pile supported.

d. Facility Administration Building - This structure is two stories in height and maximum column loads are about 80 tons with no net uplift. For these conditions, drilled-and-underreamed caisson foundations are the most economical solution and are therefore recommended. The long term settlement of these footings can be considered acceptable if they are sized to keep the dead load bearing pressure low.

e. Refrigeration Building - The building superstructure is relatively light hence drilled-and-underreamed caisson foundations should be used. The refrigeration equipment within the building is all supported at grade, independent of the building foundations. It was determined that the large helium and liquid nitrogen compressors require pile supported foundations ince the equipment weight and the associated mass requirement could not be carried on a spread footing without incurring large settlements. That the vibration of this equipment could magnify the effect of unequal dead load bearing pressure on an individual spread footing and cause tipping was also considered in the decision to place the large compressors on piles.

3.0 Chamber Elevation

3.1 Alternates - Three basic concepts for the elevation of Chamber A with respect to grade were evaluated:

I Surface support with only a nominal pit below ground floor level in the building

II Partial burial of the chamber to bring the working level of a side entry door as close to ground floor as possible.

III Total burial of the chamber in a silo type foundation to facilitate top loading of all test components.

3.2 Evaluation - These three concepts were evaluated with respect to excavation, ground water, buoyancy, related super structure requirements, vehicle loading efficiency, access to chamber equipment for servicing, future expansion versatility, piping layout, construction schedule, and total relative cost of structure.

Concept I has advantageous characteristics except for the vehicle handling inefficiency and the related superstructure requirements. Buoyancy, ground water, and excavation considerations for this scheme are minimal. Access, piping, future expansion and construction schedule considerations are good while the relative cost of the structure is average.

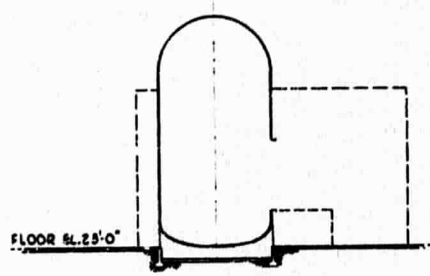
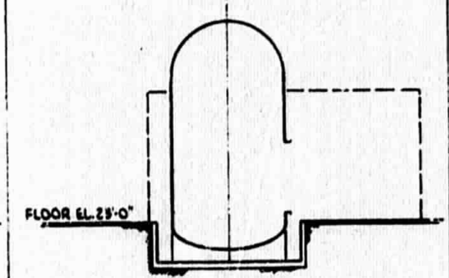
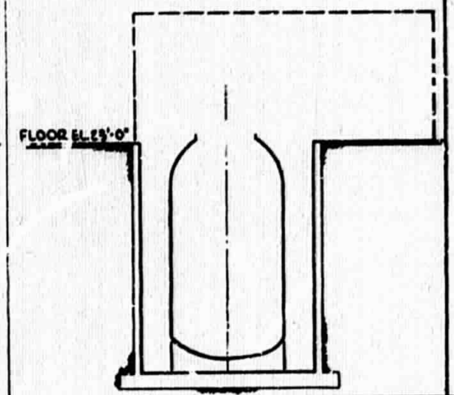
Concept II is good with respect to all evaluation criteria except ground water and buoyancy which are not serious problems at this elevation. The construction schedule and total relative cost of the structure are average. This concept appears to have the most important advantages when considering the entire facility and all related components.

Concept III is obviously very poor with respect to buoyancy, ground water, excavation and construction schedule. All other evaluations are poor except vehicle loading efficiency which is excellent and related superstructure which is good. The total relative cost of substructure and superstructure is very poor and construction problems would be large.

A summary of the above evaluation is given on Fig. XII-1.

3.3 Recommendation - Of the three chamber foundation concepts evaluated, 1) Support at grade; 2) Partial burial; 3) Total burial, the support at grade has advantages with respect to foundations alone but has a poor vehicle loading efficiency and requires the largest building. The totally buried concept has serious buoyancy, construction schedule and cost problems, although requiring the smallest above ground building. The partially buried approach appears to strike a balance which provides vehicle loading efficiency and minimum superstructure while keep the buoyancy and ground water problems within reason and it is therefore recommended.

CHAMBER ELEVATION · EFFECT ON FOUNDATION

CHAMBER ELEVATION CONCEPT	SCHEME A	SCHEME B	SCHEME C
			
EVALUATION CRITERIA			
EXCAVATION	G	A	VP
GROUND WATER	G	P	VP
BUOYANCY	E	A	VP
RELATED STRUCTURE	P	G	G
VEHICLE LOADING EFFICIENCY	P	G	E
ACCESS FOR SERVICING	G	G	P
FUTURE EXPANSION	G	G	P
PIPING LAYOUT	G	G	P
CONSTRUCTION SCHEDULE	G	A	VP
RELATIVE COST	A	A	VP

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FOUNDATION EVALUATION

4165 | FIG XII-1

II

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SECTION XIII
FACILITY LAYOUT

1.0 Single Chamber Complex - Layout studies were made initially on the arrangement of structures to serve single chamber complexes. The schemes best meeting the requirements are illustrated on Fig. XIII-1 for a large chamber such as A, and Fig. XIII-2 for smaller chambers such as Chamber B.

These schemes reflect the desirability to locate the control room, refrigeration, and roughing pumps near the chamber to shorten wiring and piping and the necessity for a high crane bay to set up test articles.

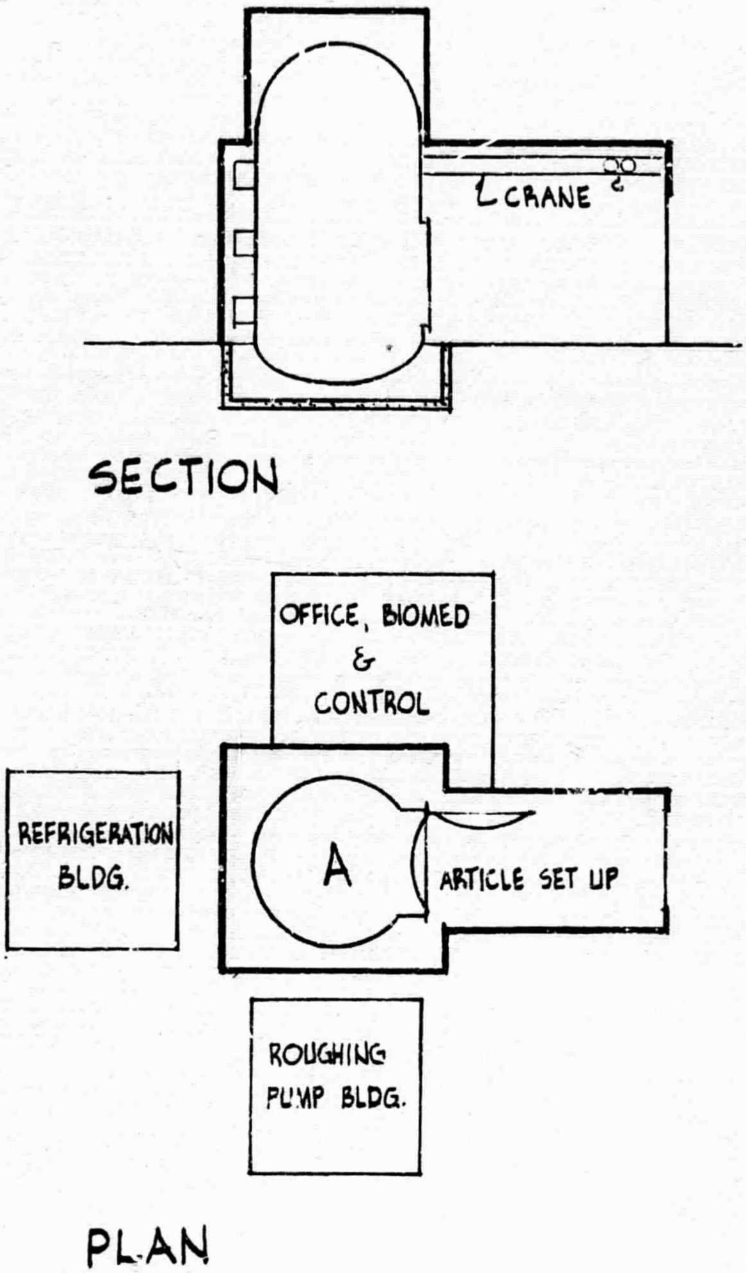
2.0 Combined Chamber Complex - In later stages of the study, diagrams were made to determine the most desirable arrangement for a complex to serve Chambers A and B. As a result the arrangement shown on Fig. XIII-3 was selected. This arrangement combines the features of the layout developed for individual chambers. A common area between the chambers is provided for test setup and the space occupied by Chamber A door swing is also used for delivery of test articles. The refrigeration plant is located nearest the source of greatest load as is the rough pump house. The Administration Building is placed on the campus side of the facility

Mechanical units such as tankage substations, etc., are shielded from the campus by the high bay building.

3.0 Alternate Control Room Location - Further studies were made of the arrangement of the Administration Building. Two alternates were reviewed. Fig. XIII-4 shows the unitized control rooms located on the ground floor opposite each chamber with a centralized biomedical area. Offices are located on the upper floor above the control room wings. Fig. XIII-5 shows a common control room located on the upper level with biomed and office areas on the ground floor. This latter scheme appears to provide shorter wiring, centralized location of the data handling equipment, and better integration of the test team. It also provides some viewing of the test article setup area on the ground floor. This is the recommended arrangement.

4.0 <u>Alternate Biomed and Office Arrangements</u> - Additional studies were made to determine the best arrangement of offices and biomed spaces on the ground floor.

Two major alternates with minor variations were examined. Fig. XIII-6 shows the biomed area located adjacent and parallel to the long direction of the chamber building with the offices located immediately beyond. Fig. XIII-7 shows the offices grouped on one side of the floor area with biomed grouped on the other. The latter scheme is most desirable from the standpoint of traffic and proximity of related functions, and is recommended.



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SINGLE CHAMBER COMPLEX
CHAMBER A

JOB No 4185
DWG NO FIG. XIII - 1
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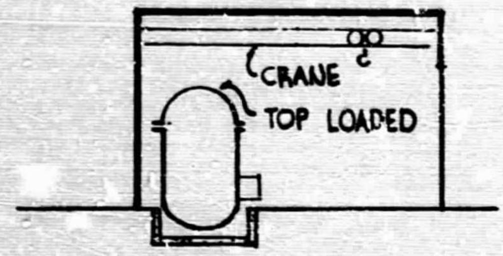

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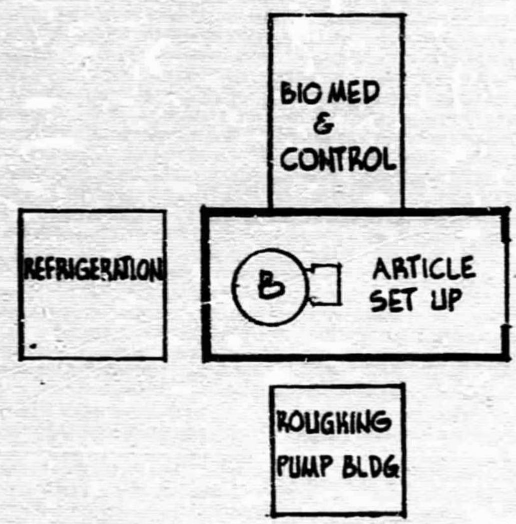
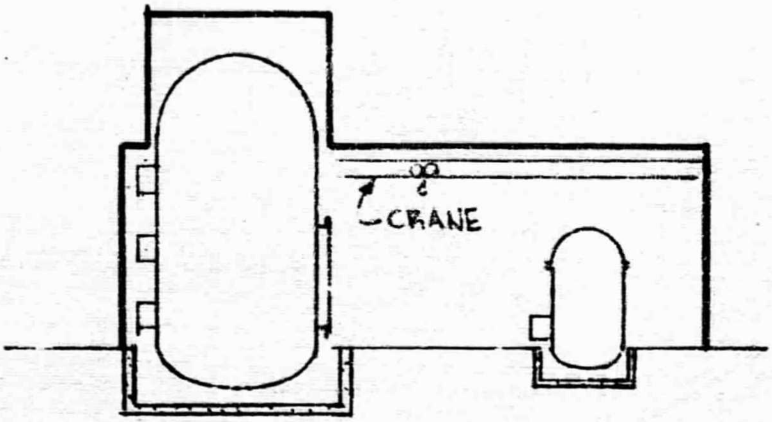
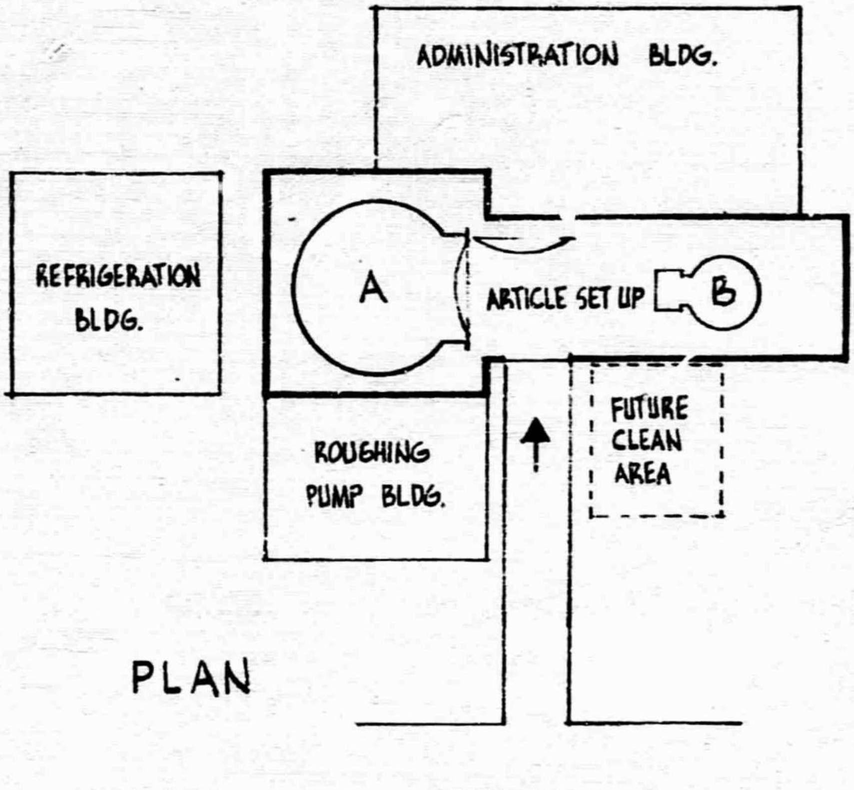


PLAN

BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT № NAS 9-413	JOB № 4185
	SINGLE CHAMBER COMPLEX CHAMBER B	DWG. NO. FIG. XIII - 2



SECTION



PLAN

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
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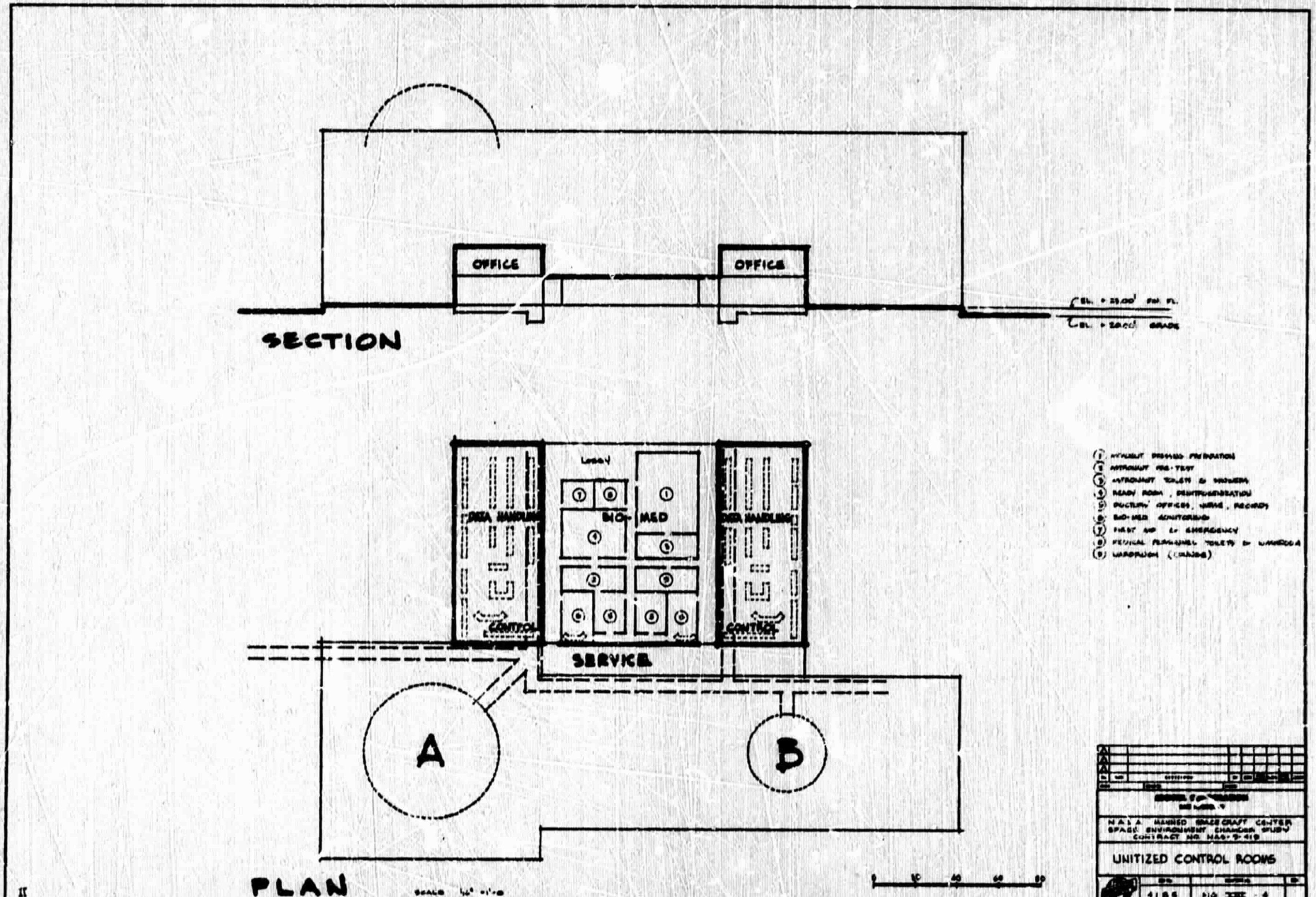
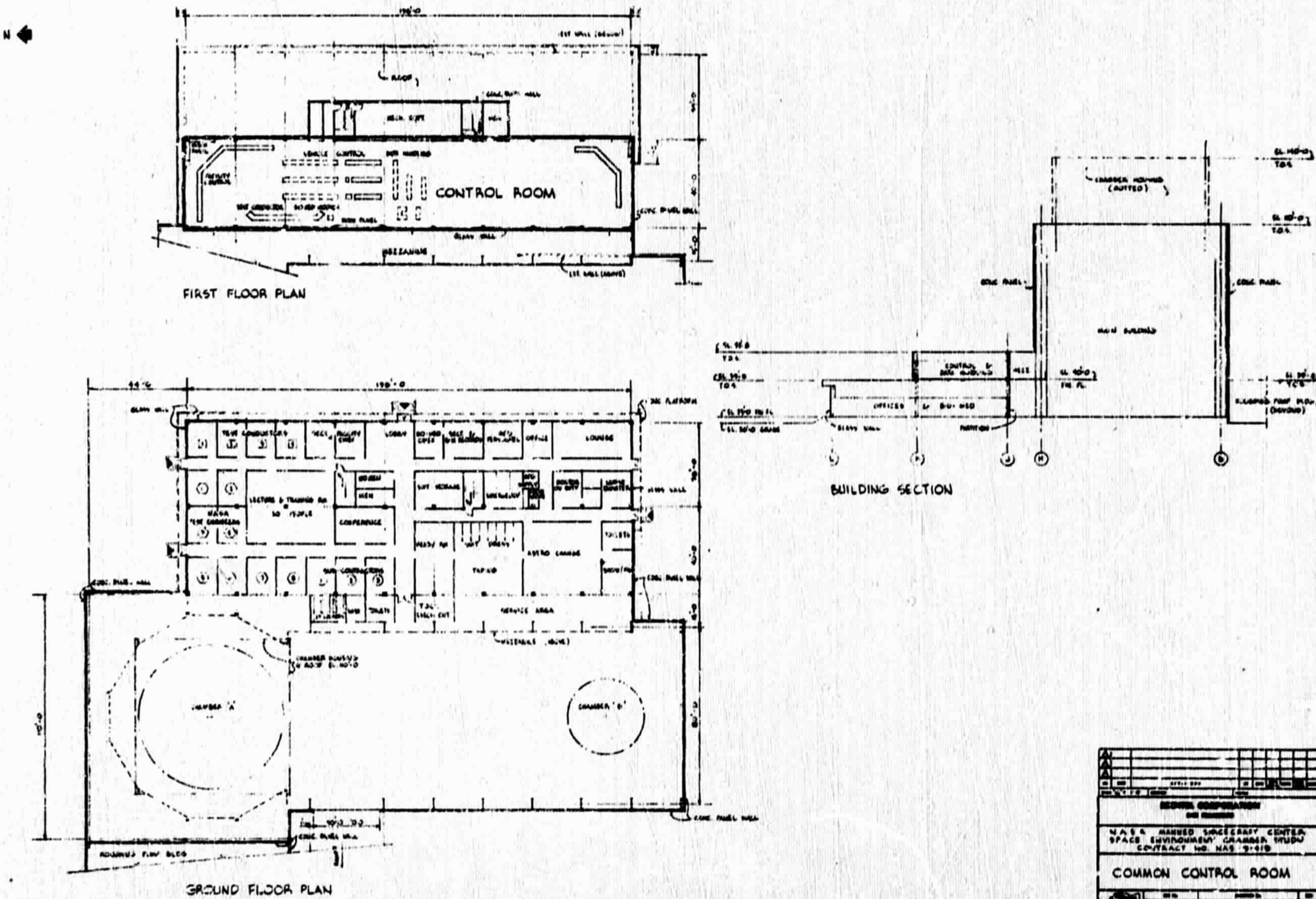
BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT Nº NAS-9-419	JOB No 4185	REV.
	COMBINED CHAMBER COMPLEX CHAMBERS A & B	DWG. NO. FIG. XIII 3	

G-231-E 4-14-59 II



OFFICE
OFFICE
EL. + 25.00' FIN. FL.
EL. + 20.00' GRADE
SECTION
LOBBY
BIO-MED
DATA HANDLING
CONTROL
DATA HANDLING
CONTROL
SERVICE
A
B
ASTRONAUT PRE-TEST
BIO-MED MONITORING
FIRST AID & EMERGENCY
N.A.S.A. MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NR NAS-9-419
UNITIZED CONTROL ROOMS
PLAN
0 20 40 60 80



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CONTRACT NO. NAS 9-419

COMMON CONTROL ROOM

4185 FIG. XIII - 5

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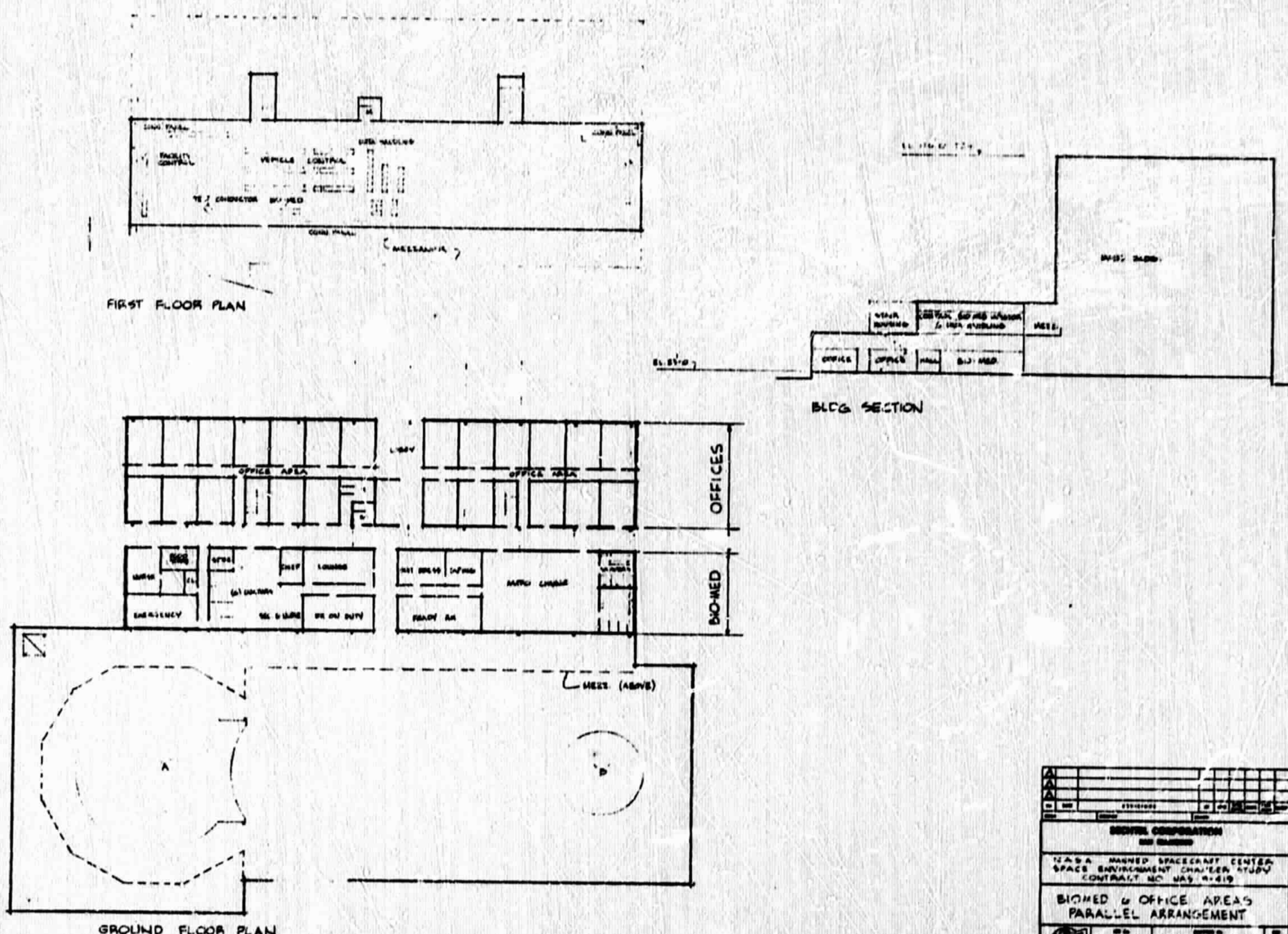

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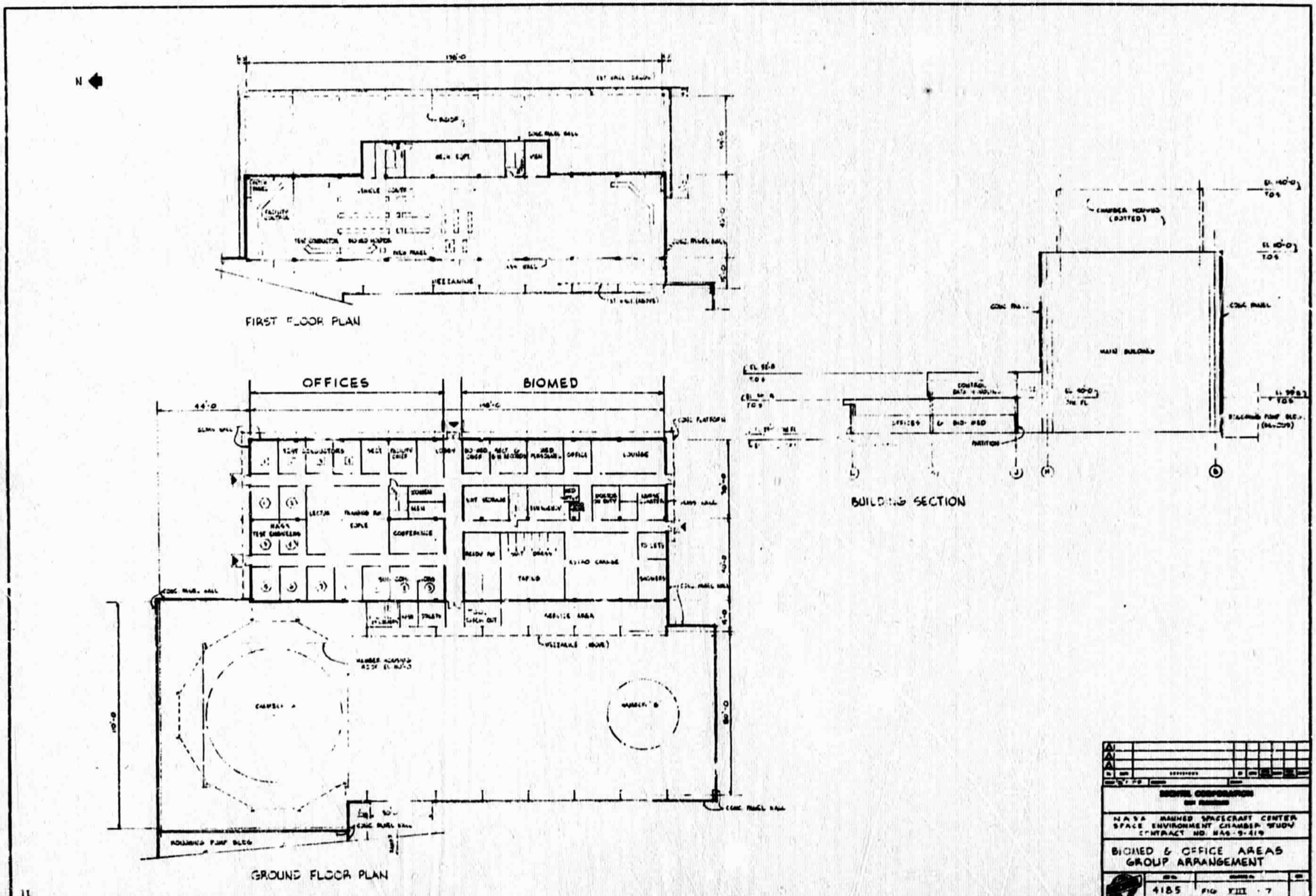
CONTRACT NO. NAS 9-419

BIOMED & OFFICE AREAS
PARALLEL ARRANGEMENT

4185 FIG XIII - 6

II



FIRST FLOOR PLAN
OFFICES
BIOMED
GROUND FLOOR PLAN
BUILDING SECTION
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NO. NAS-9-419
BIOMED & OFFICE AREAS
GROUP ARRANGEMENT
4185
FIG XIII - 7

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SECTION XIV
OPERATIONS

1.0 Checkout and Acceptance Tests

1.1 General - Each component and system of the facility complex will undergo many individual tests during fabrication, assembly, and "de-bugging". In addition to these, final tests will be conducted prior to their use in overall chamber operation.

1.2 Vessel (including locks)

1.2.1 Leak Check - After the vessel and locks are fabricated with all penetrations either installed or balnked off, the chamber is pumped down to about 5×10^{-3} mm with a roughing system. A line is connected between the inlet of the roughing pump system and a helium mass spectrometer leak detector. Helium is applied, either in one operation or sequentially by zones, to the outside of the entire shell of the chamber to insure that no leaks exist. This test is done before the installation of the normal vacuum pumping system, solar simulator windows, nitrogen and/or helium panels, and other chamber internals. It should be repeated after each of these major components are added.

1.2.2 Load Test - A load test is conducted to insure the structural integrity of the vessel. This test consists of roughing down the chamber to a few millimeters while handing weights from the vessel in the same manner as the vehicle and chamber components would be supported. These weights exceed the actual component weights by about 15%.

1.3 Vacuum System

1.3.1 Leak Check - After the complete vacuum system is installed, a helium leak check of it is performed. With the high vacuum valves closed, the roughing lines closed, and the diffusion pumps operating, the leak detector samples the fore-lines of the diffusion pumps. While this sampling is taking place, the entire vacuum system is bathed externally with helium. Particular attention is given to valves, connections, and seals.

1.3.2 Pumping Speed Test - With calibrated gas sources located in small separate compartments at the entrance to the vessel pumping ports, the diffusion pump speeds are tested.

With the high vacuum valves closed, the speed of the roughing pump system is also tested.

1.4 Cryogenic Systems

1.4.1 Refrigeration Plants - After the plants are completed, a test is run to test their capability to handle maximum heat loads at required inlet temperature, outlet temperature, flow rate, pressure drop, and test duration. This test is conducted with a simulated cryopanel load located outside the chamber. The test load is the same flow resistance as the cryopanels and abosrbs the same amount of heat at operating temperature. It consists of a simple set of coils operating in controlled temperature air.

1.4.2 Cryopanels - After installation, the cryopanels are helium leak-checked by evacuating them internally and bathing them externally in helium. The variation in the temperature of the cryopanel surface is determined by operating them at design temperature under maximum heat load in vacuum. The heat loads are provided by mock heat sources or by the solar simulator and lunar plane. In either case, the heat load exceeds the design heat load by about 15%.

1.5 Radiation Simulators

1.5.1 Collimation - After the simulators are installed in the chamber, the collimation of their beams is checked geometrically. This test may be done in air and may take many forms. One of these would consist of measuring the increase in diameter with length of a light beam which is formed by a hole in a plate facing the simulator.

1.5.2 Heat Generation - The simulator beam is tested for its accuracy in simulating the solar heat generation in vehicle surface materials. A calorimetric test is conducted using a water-cooled plate made of various vehicle surface material. These tests are conducted in vacuum to minimize heat losses from the calorimetric plate.

1.5.3 Intensity Variation - The variation in the beam intensity is measured by the same technique utilized in 1.4.2 or with photo-cells.

1.6 Repressurization System

1.6.1 Pressure vs Time Response - After installation of all repressurization system components and before installation of any shock-susceptible chamber components, rapid chamber repressurization experiments are conducted. The sequence of valve actuation is varied until the required time response is obtained for the partial pressure of oxygen and for the total system pressure.

1.6.2 Mechanical Loads - Using the repressurization sequence evolved in 1.6.1, measurements are made of noise, vibration, and dynamic pressures generated in the chamber. If these measurements indicate that satisfactory conditions exist, the tests are repeated with simulated chamber components and a simulated vehicle in the chamber. The tests are then repeated with "suited" animals in the chamber and finally done with a man in the chamber. When all these tests have been finished and satisfactory results obtained, the installation of the rest of the chamber components can proceed. A final series of tests are run after the installation is complete.

1.7 Lunar Plane

1.7.1 Leak Check - After the cryo-tubes have been welded in place, a helium leak check is made by evacuating the tubes internally and bathing them externally in helium.

1.7.2 Performance Check - Under vacuum and cold heat sink conditions, the temperature uniformity of the lunar plane surface is examined for all ranges of temperature operation. The increase in heat load on the heat sink panels is also measured at the same time and compared to the design specifications. Particular attention is given to the high temperature lunar plane condition which represents the worst temperature non-uniformity and the greatest heat load. This test will expose any malfunctioning heater or any heater which does not make adequate thermal contact with the underside of the lunar plane.

1.8 Overall Chamber Checkout -

1.8.1 General - After each component and system is satisfactorily tested, a final performance test of the overall chamber is made.

1.8.2 Normal Operation - With vacuum system at normal operating condition, with helium and/or nitrogen systems at maximum operating condition, with radiation simulators and lunar plane operating at conditions corresponding to maximum heat load, and with calibrated leaks equivalent to the design leakages for the vehicle and space suits present within the chamber, the required vacuum level and heat sink panel temperatures are checked.

This test is repeated for variations in the solar simulator-lunar plane combinations to insure that the overall chamber system can tolerate the worst combination.

1.8.3 Emergency Operation - With the overall chamber system operating at normal conditions and a mock vehicle present within the chamber, the repressurization system is tested.

2.0 Startup of a Chamber

2.1 General - The startup of a chamber requires the preparation and checkout of many internal chamber components and of several external systems and sub-systems. In this section, a step-by-step procedure for chamber startup is presented with the assumption that external systems such as the cryogenic plants have already been prepared for operation and are in a standby condition. These startup procedures apply both to Chamber A and to Chamber B except where differences are noted.

2.2 Preparation for Startup - All chamber components, sub-systems, and instrumentation are checked out prior to startup. This includes:

a. All disturbed seals, entries, and penetrations should be leak-checked individually.

b. Solar simulator lamps should be checked out.

c. Helium and nitrogen systems should be checked-out by use of their external bypass which serves as a mock chamber load.

d. Lunar plane system should be checked-out.

e. All key instrumentation and valvesshould be checked-out.

f. All vehicle systems should be checked-out and astronauts should assume their test positions.

g. All soiled surfaces should be cleaned using appropriate cleaners such as acetone, water, alcohol, etc.

h. Vehicle is loaded with simulated cryogenic fuel (if chamber closure and pumpdown take too long, the mock fuel may be loaded after pumpdown through a penetration in the chamber wall).

i. All personnel should leave the chamber and a foolproof check made that none remain.

j. All airlocks should be closed and leaked-checked.

2.3 Vacuum Pumpdown

2.3.1 Chamber "A" - The following steps are followed for startup of the Chamber "A" vacuum pumpdown:

a. Check that all vacuum valves ahead of diffusion pumps are closed.

b. Check that the isolation valve ahead of stage I of the blower cascade is closed any bypass or secondary roughing line valve connecting stage II to the main roughing header is open.

c. Check that the roughing line isolation valve to Chamber A is open and to Chamber B is closed.

d. Check that on Chamber A, all air admittance valves and emergency repressurization valves and similar devices are closed.

e. Check that cooling water is flowing in the appropriate quantities and at the proper inlet temperatures, to all pumping stages (II, III, IV & V) of the roughing system and all intercoolers between these stages.

f. Start the roughing system blower and mechanical pump drive motors.

g. Let rough pumping proceed, periodically monitoring pressures and pump down times, and comparing the results with design and test data charted

h. When the chamber pressure reaches a value of the order of 5 torr, establish the cooling water supply to stage I of the blower cascade and the interstage cooler following it, in the appropriate quantity and at the proper inlet temperature.

i. At 2 torr chamber pressure, stage I of the blower cascade will automatically cut in and commence operation.

j. As soon as step (i) is completed, open the 36 inch butterfly valve ahead of blower stage #1 and close the secondary roughing or bypass valve (20") ahead of stage II.

k. Continue roughing the chamber until 2 hours before the time that the design and test data indicate thechamber pressure will reach a value of 3×10^{-3} torr. This will be about 6 to 7 hours after roughing is started.

l. Check that all diffusion pump foreline valves are open and that cooling water is flowing in the appropraite quantities and at the proper inlet temperature to the diffusion pump backing systems.

m. Start the diffusion pump backing systems and evacuate the diffusion pumps to a pressure level of the order of 1 torr.

n. When step (m) is complete, establish cooling water flows at the proper rates through the following circuits of all diffusion pump stations:

(1) Upper cooling coils of pump body and cold cap.

(2) Lower cooling coils of pump body.

(3) Large isolation valve (48") body cooling circuits and "transition piece" cooling circuits.

o. Check diffusion pump foreline pressures (Thermocouple Gauges). When they reach a level of the order of 1 torr, switch on diffusion pump heater power supply. Note: The warm up time of the pumps is of the order of 1 hour, so that by the time the chamber pressure reaches 3×10^{-3} torr all pumps will be hot and completely operative.

p. When the indicated chamber pressure is 3×10^{-3} torr open the isolation valves of all 4 type 'A' pumping stations. Monitor foreline pressures and compare with test data.

q. Close the main roughing valve to Chamber "A".

r. As the chamber pressure drops below 10^{-3} torr more diffusion pumps may be places "on stream", because the Type 'A' stations are now in a region of "stable" operation (NTN-12) and the backing system is capable of handling the throughput of further pumps.

s. Gradually and in accordance with a "test" established schedule, place groups of Type 'B' stations "on stream" by opening the large valves ahead of them. By the time the chamber pressure has reached a value of 6×10^{-4} torr to 8×10^{-4} torr, all pumping stations Type 'A' and Type 'B' will be "on stream". Monitor their performance by taking foreline pressure readings.

t. At 2×10^{-4} torr "Cryopumping" will be fully effective and a rapid chamber pressure drop is to be anticipated.

2.3.2 Chamber "B" - The precedures outlined for Chamber "A" apply for Chamber "B" with the following variations:

a. No change (Also refer to Step (k) below for simultaneous action)

b. No change

c. Check that the roughing line isolation valve to Chamber B is open and to Chamber A is closed.

d. Reference is to Chamber B, otherwise unchanged.

e. No change

f. No change

g. No change

h. No change

i. No change

j. No change

k. Prepare to place diffusion pumping system in operation simultaneously with roughing system, in view of short pumping cycle desired. Follow steps (l) through (r) simultaneously with steps (a) through (j) preceding.

l. No change

m. No change

n. No change

o. No change

p. No change

q. No change

r. No change

s. No change

t. At 10^{-4} torr a stable "ultimate" pressure level will be reached balancing pump throughput against "specified leak x 2" i.e. about 25.6 torr lit/sec.

2.4 Chamber Cooldown

2.4.1 Heat Sink - The nitrogen reliquefier is prepared for operation and started so that liquid nitrogen at approximately 80° K is available when the chamber pressure drops to 1×10^{-3} mm Hg. (Instructions for preparation, startup, and operation are found in another Section.) The valves from the nitrogen reliquefier to the chamber are opened and the inlet valves to the cryopanels are opened. The temperature and pressure control valves on the outlet lines of the cryopanels are set and put on automatic operation.

2.4.2 Cryo-Surface Pumps - The helium refrigeration equipment is prepared for operation and started so that dense gaseous helium at approximately 15°K is available when Chamber "A" pressure drops to 1×10^{-4} mm Hg. (Instructions for preparation, startup, and operation are found in another section.) The valves from the helium refrigeration unit to the chamber are opened and the inlet valves to the cryopanels are opened. The temperature and pressure control valves on the outlet line of the cryopanels are set and put on automatic operation.

2.5 Solar Simulator Light-Up - When an equilibrium chamber pressure is nearly attained and all systems are operating satisfactorily, the solar simulator lamps are turned on after coolant flow is established.

2.6 Lunar Plane Startup

2.6.1 General - The lunar plane temperature will be adjusted to the level required by the experiment.

2.6.2 Cold Surface - For a cold lunar plane surface the inlet valves for liquid nitrogen flow to the lunar plane are opened. The temperature and pressure control valves on the outlet lines are set and put on automatic operation.

2.6.3 Warm Surface - For a warm lunar plane surface, the flow of liquid nitrogen is stopped and the electrical heaters are started. The heater power supplies are set and put on automatic temperature control.

2.7 Final Checkout - Before the vehicle test experiment begins, the following checks should be made:

a. All flows, temperatures, and pressures are analyzed.
b. All chamber instruments indicate they are in working order.
c. All vehicle systems, vehicle components, and astronauts are in satisfactory condition.

3.0 Normal Operation and Maintenance of a Chamber

3.1 Cryo-Panels - The amount of refrigerant flowing through each section of cryopanels is governed by the temperature of the refrigerant leaving the panels. As the heat load within the chamber increases, the temperature control valves on the outlet lines gradually open to increase the flow. When the heat load is reduced, the temperature control valves gradually close to restrict the flow. If the heat load should increase to a point where liquid nitrogen from the refrigeration equipment is inadequate, provisions are made so that additional refrigerant is available from storage tanks to supplement the flow.

Two operators per shift plus one maintenance "on-call" man per shift should be adequate for operating the nitrogen and helium refrigeration units at the same location. The helium reliquefier at another location should require one operator and one maintenance "on-call" man per shift.

3.2 Vacuum System - No special maintenance is anticipated during the normal operating periods of 14-30 days for either of the test chambers. However, normal equipment checks are advised "between" operations. The extent of such checks depends entirely on the actual time interval between operations. All levels of oils in the roughing system should be checked and a periodic check of levels of working fluid in the diffusion pumps (every 3000 hours of operation approx.), using the level "plug" in the pump body, is advised. All power operated valves should be checked for response and function.

It is estimated that 2 operators can efficiently and effectively operate the vacuum system for either Chamber A or B. If both chambers are operated simultaneously, one operator should be assigned to the "Roughing System" with two further operators, one for each chamber diffusion pump system (total required - 3).

3.3 Radiation Simulators - The voltage, current and coolant flow for each lamp should be monitored and recorded. Photo-cells located in the optical system should also be observed to detect a drop-off in lamp output prior to failure. When the drop-off reaches an intolerable level, the lamp can be replaced without interrupting chamber operation.

Approximately two men will be required to monitor, control, and maintain the simulators during normal operation.

4.0 Normal Shutdown of a Chamber -

4.1 Radiation Simulators - The power to the radiation simulators is turned off and the coolant flow stopped. If the lunar plane is warm, the electrical heaters are turned off.

4.2 Cryo-surface Warm-Up - The flow of helium through the panels is stopped by closing the valves to and from the refrigeration unit. Warm helium is then circulated through the panels to warm them. The flow of liquid nitrogen through the heat sink and lunar plane panels is then stopped by closing the valves to and from the nitrogen reliquefier. Warm nitrogen is then circulated through the panels to warm them.

4.3 Vacuum System Shut-Down

4.3.1 Roughing System - The procedure which can be followed any time after initial chamber pumpdown is:

a. Close the main roughing valve to the chamber being evacuated.

b. "Crack" open the vent valves of the roughing system.

c. Discontinue the power supply to the drive motors of the blower cascade and mechanical pumps of the roughing system. Open vent valves fully.

d. Discontinue the cooling water supply to all stages of the roughing system.

4.3.2 Diffusion Pump System - The procedure which is initiated after helium and nitrogen panels warm up is:

a. Close all of the high vacuum valves (48") ahead of the diffusion pump stations 'A' & 'B'.

b. Repressurize the vacuum chamber by following the established procedures for "normal" repressurization.

c. Shut off the power supply to all of the diffusion pump heaters (Note : Continue to operate the backing system).

d. Circulate cooling water through the diffusion pump "quick cool" circuits, if fast cool down is desired.

e. When the diffusion pump boiler areas are cooled to about 70°F, prepare to shut down the backing system.

f. "Crack" the backing system vent valves.

g. Shut off all backing system pump motors and open vent valves fully.

4.4 Repressurization - The chamber should be vented to air slowly through the normal repressurizaton valve. The airlocks can then be opened and the normal air circulation system in the chamber should be turned on.

5.0 Emergency Chamber Conditions

5.1 Rapid Repressurization of a Chamber - If a man in the chamber requires emergency repressurization, the repressurization system described elsewhere is actuated. To protect the vacuum system from severe contamination and possible explosive reactions, the high vacuum valves are closed immediately. From that time, the normal shutdown sequence should be followed as quickly as possible.

5.2 Leak in the Cryo-System - Several magnitudes of leaks might occur. These are described separately as follows.

a. Major Pipe Rupture - If a major pipe rupture occurs, approximately 150 gallons of nitrogen might be released inside the chamber. This would solidify immediately as snow or hail, and then vaporize as it picks up heat. As it vaporizes, it will be pumped out by the cryopanels. The pressure and temperature control valves will close and shut off the flow to the ruptured panel section. The remaining panel sections will continure to operate. The vacuum in the chamber will be lost because of the nitrogen released and the high vacuum valves should be closed immediately.

b. Medium Leak - If a medium leak should occur, and the holes are sufficiently large enough to allow liquid to seep out, there is a possibility of this liquid freezing and closing the hole. If this does not happen, the effect will be similar to that of a large rupture, but with a slower pressure change within the chamber. The high vacuum valves may or may not have to be closed, depending on the resultant pressure.

c. Small Leak - A small leak may cause a pressure change within the chamber only to the extent that it would overload the cryopump. A leak of this sort, probably would not be detected immediately in the liquid nitrogen system. It could be detected, however, on the chamber monitor panel. If the leak is not large enough to overload the cryopumps, the increase in pressure would be slight and would be corrected as soon as the cryopanels adjust themselves to handle the higher heat load. In this case, the high vacuum valves would probably be left open.

5.3 Leak in the Vacuum Envelope - A large leak in the vacuum envelope would require immediate closing of the high vacuum valves-and termination of the vehicle test. Smaller leaks may be tolerated if the type of vehicle experiment permits. If operation much above 10^{-3}mm is to be permitted, the diffusion pump system should be shutdown (as per normal procedures) and the roughing pump system should be started up and the roughing line valve opened.

6.0 Operation of the Gaseous Helium Plant

6.1 General - The following paragraphs cover purging, warm space chamber startup, cold space chamber startup, normal operation, and shutdown procedures, and initial charging of helium storage tank.

6.2 General Operating Instructions - The helium storage tank is evacuated by the high-vacuum system connected through the makeup dehydrator and the manifold from dehydrator to storage tank. After evacuation, it is filled with helium through the charging manifold.

6.3 Purge Operation - The initial purge uses nitrogen to displace the air, followed by helium purge to remove the nitrogen. Warm-up after operation would normally be by helium alone, provided that no equipment was opened.

6.4 Initial Purge - Initial purge is performed as follows:

Cooling water is started through the compressor and defrost heater. The compressor is started unloaded. Cold nitrogen is introduced into the defrost heater where it is warmed by the jacket water from the helium compressor. The nitrogen at 70°F is directed through the suction line of the compressor, the suction surge drums, the three compressor stages and their separators, intercoolers, and aftercoolers; and discharged out of separator drain valves. When the compressor suction line has been blown dry, the cooling water outlets of the intercoolers are throttled to raise the gas temperature. Nitrogen at 150°F is pumped through the compressor discharge lines into the first heat exchanger unit, through the adsorbers, through the tube side of the nitrogen evaporator (which is not supplied with liquid nitrogen until plant startup), through the Dewar compartment heat exchanger, momentarily through the expansion turbine, then bypassed through the external load circuit and return lines to the shell side of the heat exchangers and to the purge outlets.

After the nitrogen purge, the compressor drive motor is stopped and the compressor block outlet valve is closed. The compressor is then purged with helium from the helium storage tank which has previously been evacuated and filled with helium. The helium is introduced into the compressor suction line and the purge progresses through the suction surge drum, to the intercooler and separator of each stage, and to the discharge surge drum drain.

The purge is performed in sequence; the suction surge drum drain line is kep open until the purge outlet contains one-half percent of less of

nitrogen. The first stage separator drain line is then opened and the suction surge drum drain line is closed. Thepurge outlet from the first stage separator outlet drain is analyzed until it reaches one-half percent nitrogen, after which the next separator drain line is opened, the first stage separator drain closed, and the purge progresses throught the block. The compressor is bumped, once for each stage as that stage is being purged. The compressor block inlet valve is closed, the manual bypass valve opened between aftercooler outlets and suction surge drum, and the suction surge drum drain valve is opened. The compressor is then bumped to purge the third stage aftercooler and line.

The suction surge drum drain is closed, heat exchanger outlet valve opened, the purge outlet valve opened, and the return line from the heat exchanger to the compressor suction is purged until the nitrogen content at the purge outlet is one-half percent or less. The outlet valves of heat exchanger are then closed, and the vent valve downstream of the nitrogen purge inlet valve is opened as the vent point for helium purge of the defrost heater. The purge is continued until the purge outlet is one-half percent of less nitrogen. The vent valve is now closed, the purge outlet valve opened and the compressor is started unloaded.

The expansion turbine bypass valve and the inlet and outlet valves to the external load are opened. The helium compressor is then loaded by partially closing the manual bypass valve. Adjust compressor suction and discharge controller to prevent excessive withdrawal of helium from storage tank. The purge is continued through adsorber and Dewar, the external load lines, and return lines to the purge outlets until the nitrogen content at the outlets is one-half percent or less. The expansion turbine is turned over for 1 minute to purge it. The vent valve in the nitrogen purge inlet line and the exchanger bypass valve is now opened, and the heat exchanger outlet valve is closed to direct the purge through the bypass around the helium-helium heat exchanger in the Dewar to vent through the purge vent valve. The needle control valves of the flow indicators are opened to purge the interior of the Dewar compartment to the atmosphere. The purge is continued until the nitrogen content of the purge outlet at the vent valve is one-half percent or less. The compressor is then shut down and all valves closed.

6.5 Startup - To start the plant, the bypass valve between expansion turbine inlet and discharge and the bypass from discharge to the external load return line are opened; and the cryopanel shutoff valves are closed. The heat exchanger outlet valve and the compressor block inlet and outlet valves are opened. The high-vacuum system is brought to normal operating values. The pressure regulator valve from helium storage is set to its normal value.

The jacket water flow is started through the compressor system and the defrost heater and the compressor are started. The liquid level controller on the nitrogen evaporator is put on control. When the temperature of the helium drops to approximately 89°K within the Dewar compartment, the expansion turbine is started, then the expander bypass valve is closed. The expansion turbine discharge temperature is monitored until the outlet temperature matches the cryopanel temperature, then the cryopanel shutoff valves are opened and bypass is closed.

6.6 Normal Operation - The time response of the system is dependent upon the external load conditions, actual operation will indicate which values meet system requirements. There are several ways in which the system refrigeration capacity may be reduced as the external load decreases from maximum toward minimum: the turbine speed may be changed, or helium may be bled from compressor discharge to the helium storage tank to reduce the capacity of the system. The expansion turbine speed can be varied, above temperatures of 10°K, then the helium bypass through the defrost heater will be the method of control to avoid too low a temperature, helium bled to storage is the normal control.

6.7 Switching Nitrogen Adsorber Cylinders - The nitrogen adsorber cylinders must be switched every 8 hours or when a test reveals abnormal nitrogen and trace impurity concentration in the helium gas. The normal operating cycle can best be determined by monitoring plant nitrogen concentrations and establishing normal operating limits.

Precooling Cylinders - Before switching cylinders, the fresh cylinder must be precooled to operating temperature. This is accomplished by the cooling cycle during the adsorber reactivation. While the fresh cylinder is on "standby", the approximate operating temperature is maintained, and the exact operating temperature is attained by operating the cylinder in parallel with the saturated "on-stream" cylinder for approximately 5 minutes.

Switching Cylinders - Switching the nitrogen adsorber cylinder is done by precooling the reactivated cylinder to operating temperature and then bringing it into parallel service with the on-stream cylinder for a short time. Flow through the used cylinder is then stopped and the cylinder is immediately reactivated with hot helium gas.

6.8 Reactivating a Nitrogen Adsorber Cylinder - After the contaminated nitrogen adsorber cylinder is removed from service, it must be reactivated to remove the nitrogen and trace impurities from the adsorbent bed. To accomplish this, hot helium gas is passed

through the adsorbent bed during the heating cycle of the reactivation process. The cooling cycle of the reactivation process then precools the cylinder to operating temperature.

6.9 Shutdown - The refrigerator unit is shut down by slowing down the expander, then shutting down the expander. The compressor remains in operation with its pressure indicator control valve set to discharge to the helium storage tank. The compressor outlet block valve is then closed. The compressor is operated to return helium to storage tank from the system using the suction and discharge pressure controller. The liquid level controller on the nitrogen evaporator is adjusted to shut off the liquid nitrogen supply if the plant is to be warmed up. Suction pressure should be monitored and the compressor bypass valve adjusted to maintain a positive pressure at the suction of the compressor. When no further suction pressure rise occurs, shut down the compressor. Shut the Dwar valve from the external load return lines.

Shut off the helium purge to the Dewar compartment. Shut off the cooling water and jacket water flow. Drain the compressor jackets, separators and coolers, and defrost heater if freezing temperatures are anticipated. Close compressor block inlet and outlet valves. Vent compressor through suction surge drum drain using manual bypass valve from third stage discharge. Blow down to within 2 to 3 psig, the close drain valve.

7.0 Operation of Liquid Helium Plant

7.1 Preparation for Operation

Prepare the helium reliquefier for operation as follows:

a. On initial start-up, whenever the system has been opened for repairs, or whenever it is suspected that air has entered the system, the system must be purged. Purge the system with pure, dry nitrogen first and then purge the nitrogen with helium.

b. Prepare the compressor and expansion turbine for operation making sure they are properly lubricated and turn freely.

c. Be sure the adsorber cylinders inlet and outlet valves are closed.

d. Set the level control valve on the nitrogen evaporator to the proper position and be sure liquid nitrogen is supplied to the evaporator

e. Open the expansion turbine bypass valve and the helium expansion valve wide.

f. Set the pressure control valve for make-up helium to the desired position.

g. Set flash tank level control for desired liquid level.

h. Close the shutoff valves in the lines to and from the external heat load.

7.2 Operation - Once the system has been checked and prepared for operation, proceed as follows:

a. Start the compressor and allow it to reach operating temperatures before loading it to the proper discharge pressure.

b. When the compressor temperatures and pressures have stabilized, crack open the adsorber cylinder inlet valve and pressurize the adsorber cylinder to be put on stream. Open the cylinder inlet valve wide.

c. Crack open the cylinder outlet valve and pressurize the system, Open the cylinder outlet valve wide.

d. As the system cools down, maintain the compressor discharge pressure by closing in on the expansion turbine bypass valve.

e. When the turbine bypass valve is closed, adjust expansion valve to hold compressor head pressure and set it for automatic operation.

f. When the temperature of the helium out of the tube side of exchanger has dropped sufficiently, the expansion turbine can be prepared for operation.

g. Open the turbine outlet valve and slowly load the turbine by opening its inlet valve.

h. When liquid appears in the flash tank "16.20," liquid can be started to the external heat load by opening the shutoff valves in the inlet and outlet lines to the load. (See Fig. VIII-1 Vol. II)

7.3 Switching Nitrogen Adsorber Cylinders - The nitrogen adsorber cylinders must be switched every 8 hours or when a test reveals abnormal nitrogen and trace impurity concentration in the helium gas. The normal operating cycle can best be determined by monitoring plant nitrogen concentrations and establishing normal operating limits.

Precooling Cylinders - Before switching cylinders, the fresh cylinder must be precooled to operating temperature. This is accomplished by the cooling cycle during the adsorber reactivation. While the fresh cylinder is on "standby", the approximate operating temperature is maintained, and the exact operating temperature is attained by operating the cylinder in parallel with the saturated "on-stream" cylinder for approximately 5 minutes.

Switching Cylinders - Switching the nitrogen adsorber cylinder is done by precooling the reactivated cylinder to operating temperature and then bringing it into parallel service with the on-stream cylinder for a short time. Flow through the used cylinder is then stopped and the cylinder is immediately reactivated with hot helium gas.

7.4 Reactivating a Nitrogen Adsorber Cylinder- After the contaminated nitrogen adsorber cylinder is removed from service, it must be reactivated to remove the nitrogen and trace impurities from the adsorbent bed. To accomplish this, hot helium gas is passed through the adsorbent bed during the heating cycle of the reactivation process. The cooling cycle of the reactivation process then precools the cylinder to operating temperature.

7.5 Shutdown - The unit is shutdown by unloading and stopping the expander and then unloading and stopping the compressor.

8.0 Operation of Liquid Nitrogen Plant

8.1 Preparation for Start-Up - Prepare the nitrogen reliquefier for operation as follows:

a. On initial start-up, or anytime air has entered the system, completely purge the system with pure dry nitrogen from storage cylinders.

b. Prepare the compressors for operation, making sure they turn freely and are properly lubricated.

c. Determine which adsorber cylinder is to be used and close inlet and outlet valves on both cylinders.

d. Prepare expanders for operation, making sure they turn freely and are properly lubricated.

e. Set the make-up pressure control valve at the inlet to the centrifugal compressor to supply make-up gas as required.

f. Close the reciprocating nitrogen compressor inlet valve.

g. Set pressure control valve on flash tank inlet line for manual operation and open wide.

h. Close the inlet valves to both expanders.

i. Open the expander bypass valve fully.

j. Close valves to and from the external heat load.

k. Set expansion turbine inlet pressure control valve for manual operation and open wide.

8.2 Start-Up and Operation - After the system has been thoroughly checked and prepared for operation proceed as follows:

a. Start the centrifugal compressor

b. When the compressor is operating satisfactorily, open the inlet valve of the reciprocating compressor and start the compressor.

c. When both compressors are operating satisfactorily, crack open the inlet valve on the adsorber cylinder to be put into service. Slowly open the valve until the cylinder is fully pressurized.

d. Carefully open the outlet valve of the cylinder, avoiding a sudden pressure change in the cylinder, until it is fully open.

e. Start the expansion engine and open its inlet valve.

f. Hold the head pressure of the compressors by closing in on the expander bypass valve.

g. When the gas to the expansion turbine drops to approximately $-100^{o}F$ prepare to put the expansion turbine on stream and slowly open its inlet valve.

h. Slowly load the turbine to an inlet pressure of 250 psig by adjusting the inlet pressure control valve. Set valve controller for automatic operation.

i. Close in on the expander bypass valve to hold the compressor head pressure.

j. When the bypass valve is fully closed, slowly close in on the flash tank pressure control inlet valve to maintain compressor head pressure of 3000 psig and set the valve for automatic operation.

k. As the liquid level builds up in the flash tank slowly open valves to and from the external heat load until they are fully open.

l. During peak heat loads, additional liquid is added to the system by opening the liquid nitrogen storage tank outlet valve.

8.3 Shutdown - To shutdown the system, proceed as follows:

a. Slowly close the inlet valve to the expansion turbine until it is fully closed.

b. Close the turbine discharge valve and stop the turbine.

c. Open expander bypass valve and stop expansion engine.

d. Unload and stop reciprocating compressor

e. Unload and stop the centrifugal compressor.

9.0 Instrumentation and Control

9.1 Operational Functions - Sophisticated instrumentation of any kind almost always has developed difficulty in the first field installations therefore the components when feasible for this facility must be an established design, tested and proven reliable in actual on-line operation. The basic requirement of the Facility Control and Instrumentation systems is the manufacturing of satisfactory environmental conditions necessary for the conducting of tests. The Facility Control and Instrumentation is installed in standard industrial type self supporting panels located in the Central Control Room and provides for the following operational functions:

9.1.1 Roughing System - Check annunciator to determine that no abnormal start up conditions exist and depress start button for stage II

thru V, Stage V pumps will start and their running lights will come on. Stage IV, III and II will automatically start in sequence as evidenced by their running lights. Activate the PRC to stage II intake and set control point at 70 torr. Evacuation is continued until the low pressure alarm actuates at its setting of two torr. At which time the operator closes the first stage by-pass valve, starts stage one blower, and opens the 36 inch butterfly valve to stage one intake.

9.1.2 Backing System - The diffusion pump backing system is started two hours ahead of the time the chamber pressure is expected to reach a value of three torr. One start stop station with running lights is contemplated for this system.

Additional Features - A semi-graphic presentation of the backing system is shown on the upper sixteen inch portion of the panel. The graphic contains pump motor running lights actuated from contacts in the motor control circuits. A separate alarm annunciator is provided for the backing system within this panel. A master switch is provided for the running lights and annunciator with provisions for testing all panel lamps. A semi-graphic type display of all chamber diffusion pumps with running lights and annunciator functions is also provided on this panel. The diffusion pump running lights are actuated by limit switches monitoring diffusion pump valve stem position. When the valve is closed the pump is not in operation and when the valve is open the pump is in operation. An alarm function is generated whenever a diffusion pump valve closes.

9.1.3 Cryogenic System - The helium gas cryogenic pump is started locally at the refrigeration pump station. The chamber zone control valves are set at approximately 20% open with controllers set on hand control. The inlet shut-off valves to each control zone are set at the full open position.

When the temperature moves on-scale the controller for that zone is transferred to automatic control. The normal design helium inlet header pressure is 28 pounds gauge. The system should be operated at the lowest header pressure that will produce satisfactory control (the lower the pressure the greater the efficiency). To enable the automatic controllers to produce satisfactory control all control valves must operate between 20 and 80% open and the header pressure then decreased to the lowest value that will maintain this requirement. Changes in header pressure are made at the helium pump station.

The controllers are arranged in horizontal rows so that their control points are all in line. . Thus any controller deviating

from set-point is readily detected. A separate alarm annunciator is provided for monitoring abnormal pressures. A semi-graphic or a partial semi-graphic is provided on the upper sixteen inch portion of the panel which includes helium pump motor running lights actuated from auxiliary contacts in the motor control circuit. The main helium header section is shown in graphic form and one typical helium zone (one of eight) with associated instrumentation symbols.

9.1.4 Solar Simulator and Albedo - The solar simulator main control room panel is an 8 foot section and provides instrumentation for the following operational functions:

Approximately 21 start-stop stations for turning solar lamps on and off by groups. The lamp modules are arranged in 4 vertical rows by 9 high, each module having 7 lamps. The control system provides for lighting all No. 1, 2, 3, 4, 5, 6, or 7, lamps in rows No. 1, 2, or 3, simultaneously from the main board.

Profile monitors are provided to supervise lamp voltage and light output of a group of lamps simultaneously. Selector switches are provided for manual selection of the lamp group to be monitored.

The starting procedure for a group of lamps by a control station at the main control panel is as follows:

a) Turn on main power to lamp power supplies.

b) Raise lamp voltage to starting level.

c) Depress start button. All lamps should then start. Reference profile monitor for blips for solar cell output of group being started.

d) Decrease voltage to normal operating level and adjust to watt density level required.

e) Lamps that have failed to start may be detected on the profile monitor and rather than attempt to re-start from the main board the lamp should be started locally. This request may be made over the inter-communication system to the local solar simulator board operator. During operation the profile monitor is used to view all lamps by groups, that is all No. 1's then all No. 2's, etc. Adjustments may be made to increase or decrease all like numbered lamps. This increase or decrease will consist of a zero shift type of change, that is an equal change of all lamps in that group (trimming of

individual lamp voltage changes will be made locally). Voltage regulators are provided in the main power source so that load changes due to starting by groups will not require re-adjustment of those groups already started.

9.1.5 <u>Heat Sinks</u> - The liquid N_2 pumps are started locally at the refrigeration facility pump station plant. All control zone inlet shut-off valves are set to full open. The 32 temperature control valves installed on the zone outlets are set to about 20% open with controllers set on hand control.

The five intermediate header pressure controllers are set for manual control and their control valves set to 50% open.

When the pressure moves on-scale the controller for that intermediate header is transfered to automatic control and set to control at the design value of 78 psia. (No elevation corrections are included in this value, all transmitters are installed at their respective chamber outlet elevations. Thus each pressure controller is controlling at different pressures due to different elevations of the sensing element and this condition is desirable). The supply header normal design pressure is 100 psia.

When the temperature moves on-scale the zone temperature controllers for that zone are transferred to automatic control and set to control at the normal design value of 87° K. The pressure controllers are then re-adjusted to control at the highest pressure setting that allows the control valves to operate between 20% and 80% open.

The controllers are arranged in horizontal rows so that their control points are in line, thus any controller deviating from set-point is readily detected.

A separate alarm annunciator is provided for monitoring abnormally low zone outlet pressures. A semi-graphic or a partial semi-graphic is provided on the upper sixteen inch portion of the panel which includes N_2 pump motor running lights actuated from auxillary contacts in the motor control circuits. The main N_2 header section is shown in graphic form and one typical N_2 zone (one of 32) with associated instrumentation symbols.

9.1.6 Lunar Plane - For operating between 300°K and 400°K the normal lunar plane temperature controllers on liquid nitrogen are transfered to manual control.

The liquid nitrogen header is connected by valving and manifolding so that gas from the N_2 compressor discharge re-circulates thru the lunar plane nitrogen manifold which helps to reduce the temperature gradiant.

The electric heaters are energized and the lunar plane is raised to a temperature of 300°K on manual control and then transfered to automatic control.

A separate annunciator is provided for monitoring abnormally high temperatures and high current to the lunarplane heating elements.

SECTION XV
CONSTRUCTION SCHEDULES

1.0 Types of Projects - Schedules are presented in Figs. XV-1 and XV-2 for two types of projects: The "Prime Contract-Complete Bid Package" and the "Partial Bid Package". The following discussion concerns these and also includes some comments relative to an evaluation of the "Cost Plus Fixed Fee-Turnkey", type of project.

2.0 Partial Bid Package - The "Partial Bid Package" form of construction project is recommended as it provides the most expeditious and reasonable schedule available with normal contractual procedures. This approach is estimated to provide the facility with both chambers ready for operation 24 months after start of design, with minor premium costs. This schedule is illustrated by Fig. XV-2 and is based on a June 1, 1962 start of work.

This method provides the Government with a series of bid packages of plans and/or specifications, which are awarded on a competitive bid basis for the furnishing of long lead items. A final bid package for complete construction responsibility is let by the Government for all other items including overall facility construction integration, including the long lead items, but excepting installation of leased facilities.

Breakdown of the various bid packages is as follows:

a. Criteria - Performance specifications, with vendor responsibility for finished design and construction or installation: Vessels A and B, Refrigeration System, Data Handling System.

b. Criteria - Performance specifications for engineering and manufacture with prime construction contractor responsibility for installation: Vacuum System, Radiation Simulation System, Turntables for A, and Fixed Mount for B.

c. "Partial Package" items consisting of plans and specifications for services, materials and construction: Site work, excavations and foundations, structural steel and buildings.

d. Engineering Specifications for long lead items for procurement only: Plant Air System, electrical, controls and instrumentation, mechanical equipment, 50-ton crane.

e. Prime construction contract single package for all other items and responsibility for integration of all items into complete facility ready for turnover.

This "Partial Bid Package " approach to the project has the advantage over the Prime Contract-Complete Bid Package" of providing the earliest practicable start on numerous critical items of procurement and construction. The method presents an estimated date of completion approximately five months earlier than that attainable by the "Prime Contract-Complete Bid Package" approach.

A qualification on this approach is that Vessels A and B fabrication and erection are based on two shift operation (straight time) and a swing-shift premium of $102, 000. All other work is on a straight time, single-shift basis.

3.0 Prime Contract - Complete Bid Package - The "Prime Contract -Complete Bid Package" provides the Government with a single package of plans and/or specifications for all systems and components except leased facilities (Refrigeration Plant and Data Handling System) and is illustrated by Fig. XV-1. For the leased facilities, adequate criteria and specifications are prepared to permit advertising for lease bids. A single construction contract is contemplated for the non-leased facility.

This program is administered through normal Government contractual procedures. It provides for the release of the single bid package after 7 months of engineering and is based on straight time, single-shift operation. Lead and installation times are approximately the same as for the Partial Bid Package".

4.0 Cost Plus Fixed Fee - Turnkey Package -"Cost Plus Fixed Fee-Turnkey Package"provides the Government with an operating facility utilizing competitive bid procurement managed by the contractor and its construction forces supplemented by competitive bid subcontracts. Normal Corps of Engineers design and bid evaluation reviews, and Corps of Engineers construction inspection is assumed.

While this method is not presented in detail it has numerous and distinct advantages, the most important of which is that, based on a preliminary estimate, the schedule appears to be two to three months shorter than that attainable by the "Partial Bid" method and seven to eight months shorter than by the "Prime Contract-Complete Bid Package" method.

Some of the favorable aspects of "Cost Plus Fixed Fee-Turnkey" approach are that it can provide:

a. An early and expeditious "in house" approach.

b. Earliest procurement.

c. Simultaneous development of engineering, specification writing, issue of bids and awards, fabrication and construction, etc.

d. The maximum degree of co-ordination of criteria, engineering, research and development, manufacturing, expediting, and integration of the entire facility into a coherent whole; it utilizes the concentrated efforts of a single responsible office devoted to the project.

e. Better communciation between agencies, better control of vendors and better control of "interfacing" of the several systems provided by separate specialty manufacturers.

f. Reten tention of a team, such as now exists, familiar with the basic problems involved, and in each case possessed of present "know-how" capability and experience.. There are a limited number of experienced and knowledgeable organizations available.

g. A saving in time and dollars otherwise required for engaging, educating with respect to the project, and allowing for self-education of new consultants, fabricators, or vendors.

5.0 Summary of Alternate Contractual Types of Project

ALTERNATE	Criteria and Performance Specification Only	Single or Multiple Const'n. Package	Manage: Procurement of Long Lead Items	Manage: Prime Const'n.	Manage: Constructor
Complete Bid Package	*Refrig'n. Plant *Data Handling	S	-	CE	CB
	*Refrig'n. Plant *Data Handling System Vacuum System Radiation Simulation System Chamber Vessels A&B Turntable for A	M	CE or E	CE	CB
CPFF Turnkey	(as necessary)	M	C	C	C plus CB

Lengend:
S = Single construction package
M = Multiple " "
CE = Corps of Engineers
CB = Competitive Bid Award
E = Architect-Engineer
C = Engineer-Constructor

*Complete installation by lessor

6.0 Qualifications on Schedules:

a. It is assumed that the starting date is June 1, 1962.

b. It is assumed that leased facilities are to be installed complete by lessor.

c. It is assumed that single shift, straight time operation will prevail, except that,

d. Double shift, straight time operation is assumed for Vessels A and B in the "Partial Bid" method.

NOTE: The various vendors schedules fit in reasonably well with the schedule demands of the vessel fabricator; the radiation simulator manufacturer may require double shift, straight time, but will not so state at this time.

e. Double shift, straight time operation is assumed for Vessels A and B in the Turnkey method.

f. Vacuum tests of Vessels A and B are planned to commence immediately on closing in and cleaning of vessels and the tieing in of piping and controls for the roughing and diffusion pump systems; these may be "jury-rigged", thus not requiring a completed electrical, control board and instrumentation

g. There are indications that the vendors will not bid on a radiation simulation system on a lump sum basis, although they probably would agree to manufacture on a fixed-price basis after the developmental phase.

h. Final installation, "button-up" or completion of the various facility services, must wait on the completion of the vessels; the time allowed is a period of two months after vessel vacuum test for completion of piping, electrical, controls, instrumentation and data handling etc. - mechanical equipment "button-up" is expected at the time of vessel completion.

i. The schedules are based on what are considered to be reasonable minimum time spans for the items considered.

7.0 Constraints and Critical Items:

a. The burden on engineering to produce drawings and/or specifications for the early items.

b. The long lead times of several items: Refrigeration System; Radiation Simulation System; Turntable for "A"; Vessels A and B; Data Handling System.

c. The scheduling of several activities for simultaneous performance in limited work space areas, as for "button-up" of the facilities after vessel tests.

d. The necessity for close coordination of all procurement installation, testing and integration of all components and services.

e. The necessity for maintaining the scheduled sequences for "fixed-date" items, such as vessel completion, data handling system completion, cryopanel installation, etc.

f. The schedules do not allow for delays due to weather.

g. The necessity for early site work and completion of foundations to receive Vessels A and B and the structural steel; also the necessity for early "close-in" of the buildings to provide sufficient cover for early starts on the various services.

h. It appears unlikely that research and development requirements for the project would significantly affect the completion dates shown. The major item of prototype evaluation for the radiation simulation module is allowed for in the lead time, and scheduling of the other systems possibly involved, such as emergency repressurization, instrumentation, and man-rating features do not appear critical or governing on early facility operation.

i. "Abnormal Engineering" requirements are expected to include items extending through the scheduled span to, and possibly somewhat beyond, the end dates shown; the dotted bar extension of the extension of the "Engineering" schedule item illustrates this in the figures.

j. Completion of Vessels A and B appear to set the critical end dates for the project.

8.0 Conclusions

The normal forms of Government construction projects discussed provide the following estimated completion dates:

Method	Estimated Completion Date
"Prime Contract - Complete Bid Package"	1 November 1964
"Partial Bid Package"	1 June 1964

The "Partial Bid Package" form of construction project is recommended because, within the framework of normal contractual procedures, it provides a completion date approximately five months earlier than that attainable by the "Prime Contract - Complete Bid Package".

If it is imperative to achieve the earliest completion date, the closest to 1 January 1964, then the "Cost Plus Fixed Fee - Turnkey" method appears worthy of serious consideration.

All schedules shown are estimates based on a minimum reasonable time span for each activity, but it is possible that all of the schedules proposed could be shortened by additional double and triple shift operations, at increased costs.

These schedules are subject to revision if future guidance from Government agencies is not consistent with the assumptions made in the study. Further detailed studies on bid package requirements are necessary to determine specific key dates in the schedules. The line items in the schedules shown are not necessarily the bid package breakdown which will be found best suited to meet project needs. The dates of award shown are approximate only and may indicate the initial award of a series of subpackages to accommodate the sequence of design information becoming available.

PRIME CONTRACT COMPLETE BID PACKAGE

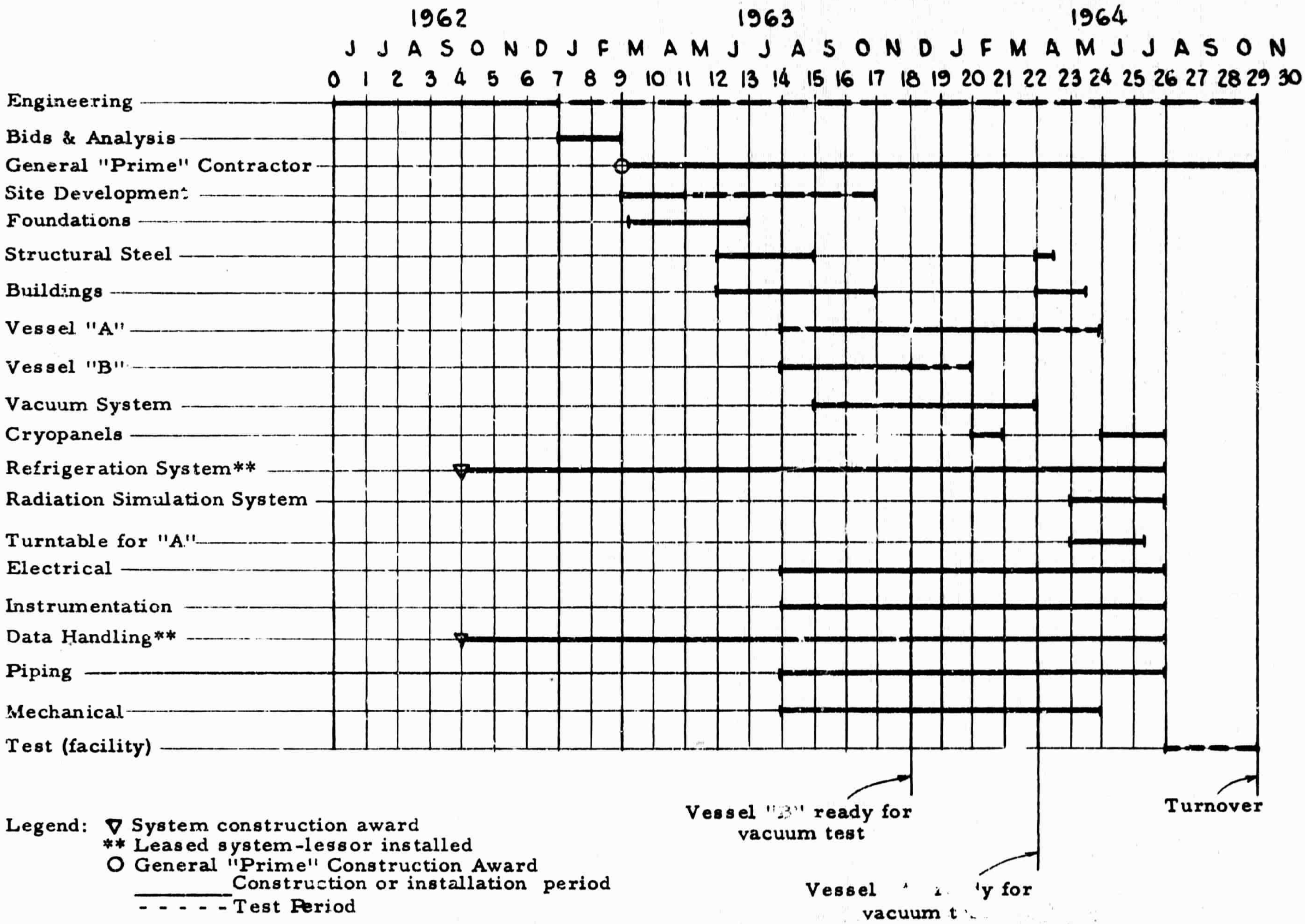

FIG. XV-1

PARTIAL BID PACKAGE

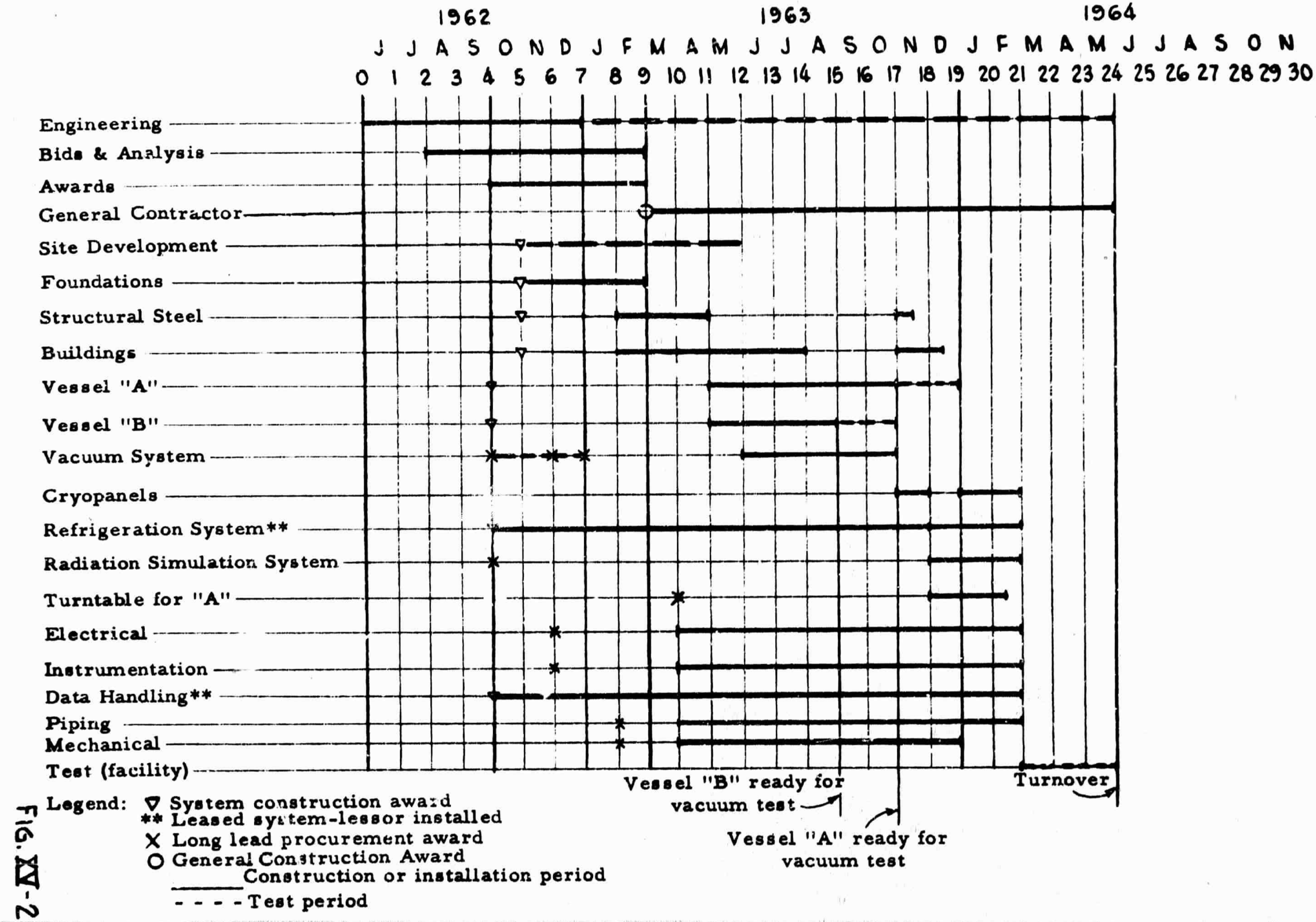

FIG. XV-2

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SECTION XVI
SPACE CHAMBER FOR SYSTEMS TEST UNDER EXTREME VACUUM
CHAMBER D

1.0 Introduction - Achieving pressures at or substantially below 10^{-10} torr in a large scale, empty metal vessel exceeds at the present time the state of high vacuum technology. The experimental facilities which can provide simulation of near space will require not only achievement of the specified pressure of 10^{-10} torr, but removal of gas molecules exuding from the test article, to maintain molecular densities which will provide the effect of near space vacuum on the tested vehicle.

Research and development efforts are indicated as follows:

1. The engineering and evaluation of the test conditions, which define the reliability of relative movement in mechanisms or components of the manned vehicle.

2. Establishing the limits of the design of a ground level simulator similar in specification to those of Chamber D.

2.0 Selection of Construction Materials

2.1 General - For the XHV (extra high vacuum) region pressures below 10^{-10} torr, the use of material of low outgassing rates and low gas permeabilities is mandatory. Any clean metallic surface when exposed to the atmosphere will quickly acquire one or more monomolecular layers of atmospheric gases. During pumping, these molecules are removed and contribute to the pumping load.

The number of molecules held on a smooth metallic surface by adsorption or chemisorption at a pressure level of 10^{-11} torr exceeds the number of molecules in a volume of a test chamber of 6 ft diameter by 6 ft high by six orders of magnitude.

To provide the basis for the computations of pumpdown times and evaluation of the blank-off limits for selected systems, it is necessary to:

a. Critically evaluate available thermodynamic data on adsorption, activation and bond energies for considered gas species and containment materials.

b. Verify by careful measurements the justification of extrapolated values of thermodynamic properties of sorption phenomena by actual measurements in experimental apparatus capable of operation in the XHV regions.

c. Experimentally determine the desorption and out gassing behavior of construction materials and most important gas components at cryogenic temperatures required for the thermal space sink simulation.

d. Determine quantitatively the depletion rates of adsorbed gases from selected confinement wall materials for each of the particular gas species. Available pumpdown data expressed as total indicated pressures, measured by ionization gauges, as a function of time are qualitative and are not applicable for the engineering design of Chamber D.

e. Determine the specific capability of various metals and construction materials to chemisorb, physisorb and desorb gases at low cryogenic temperatures to indicate the most suitable material for long-term, very low density (pressure) tests.

2.2 Recommended Research on Materials

a. Outgassing Mechanism of Containment Metals - Outgassing rates for individual gases from considered materials, as a function of time and temperature, for the range from bakeout to cryogenic temperatures.

b. Determination of thermodynamic adsorption energies and properties of important gas species on bare metallic surfaces at cryogenic temperatures.

c. Recontamination of clean surfaces by exposure to atmospheric or controlled atmospheres between tests. Effects, as derived from historical data, on containment walls should also be evaluated.

d. Permeation and diffusion rates for construction materials for considered gas species and cooling fluids from bakeout to cryogenic temperatures.

e. Reduction of the gas load by alloying, outgassing during melting, and refining of surface treatment. Use of special materials of particularly attractive properties should be included and the use of cladding by low activity and low permeability materials investigated.

3.0 Evaluation of Available Pumping Means and Allied Problems

3.1 Ion Pumping - Efficiency and operational limits of gettering ion pumps into the XHV region should be investigated. Integral arrangements for minimum impedance should be considered and tested. Operation conditions at or near cryogenic temperatures of the liquid nitrogen and liquid helium shrouds should be experimentally established for various commercial types of ion and ion getting pumps.

3.2 Extended Operation of Diffusion Pumps - The basic principle of the Langmuir mechanism of diffusion pumps does not have a theorectical limitation of the pumping mechanism, even for lowest gas densities. Recent experiments have proved, that pressure levels in empty systems in the 5×10^{-11} torr, can be reached by careful trapping of well-designed multiple jet fractionating pumps. Evaluation of the required jet stages, to provide the required compression ratios for low molecular weight gases and experimental evaluation of the effective pumping rates below 10^{-10} torr, should be undertaken to provide quantitative engineering data. Because the effective pumping speed will depend on the reduction of the backstreaming and the impedance of devices used for it, evaluation and measurement of backstreaming is essential. Selection and evaluation of advanced, highly stable pumping fluids is recommended for study. The importance of this study is enhanced by the fact that only this type of kinetic pumping removes continuously from the test volume the gas molecules of noncondensible gases, originating within the system or rejected from the tested vehicle. This fact becomes particularly important when long tests are considered or when solar simulation is used. Unless these molecules are physically removed from the system, at points of the incidence of solar radiation, a local temperature rise of the cold shroud may release bursts of gases previously condensed.

3.3 Conductance Studies - Analytical studies of the effective pumping speed and impedance should be undertaken to evaluate the overall conductance and to optimize the effectiveness of backstreaming prevention devices, pump arrangement, and manifolding configurations. The study should also include molecular behavior at the duct openings to insure sufficient effective pumping speed.

3.4 Cryocondensation and Cryoadsorption - Lowering of the containment wall temperatures to the cryogenic range, offers not only an extremely effective way of reducing the gas release from walls, but also at or near liquid helium temperatures, a remarkable capability for condensation of all gases and vapors except for hydrogen and helium. Equilibrium vapor pressures of these gases are 10^{-6} torr and 760 torr, respectively, even at 4.2°K. However, at such low temperatures

it has been observed that a very high degree of capture of these gas molecules occurs, even at very low molecular densities. Because the metallic walls release, from the solid solution within the metal, mainly hydrogen molecules. fixation of hydrogen molecules by surface forces at very low temperatures appears to be the most significant and promising mechanism for producing and maintaining vacuum levels of interplanetary space quality. Recent results at several laboratories demonstrated that surface adsorption-assisted condensation of hydrogen on very clean surfaces can remove, from free molecular motion, large quantities of gas molecules at pressure levels as low as 10^{-9} torr.

It is obvious that further development of this phenomenon below the 10^{-10} torr region holds considerable promise. At 10^{-8} torr, the effective period of such pumping is limited to several minutes or a fraction of an hour. At pressures below 10^{-10} torr, the interval which is needed to produce a complete monomolecular layer, exceeds several hours and thus may offer significant pumping means for intended near space experiments.

Investigations should cover the adsorption of residual or noncondensible gases on materials of high specific surface placed in the chamber and the adsorption on very fine virgin metal powder maintained at low cryogenic temperatures, between those of liquid helium and liquid nitrogen. Particular attention should be given to the assisted condensation and adsorption in the temperature range of $10^{\circ}K$ to $20^{\circ}K$ and the possibility of impregnation of the adsorbants with catalysts.

4.0 Evolution of Devices for the Transmission of Motion and Position Indicating

4.1 Rotary and Linear Drives - The effort should include the testing and evaluation of rotary and linear drives for the XHV environment. Experimental tests are suggested with candidate elements and semi-commercial devices, to determine their suitability for operation in the XHV range at cryogenic temperatures. Experiments with Harmonic drives, Bosch drives, magnetic drives, wobble discs, canned reluctance drives, bearing elements and geardown devices are required to verify the feasibility of transmitting motion to the test article.

4.2 Position Indicators for Measuring Torque or Relative Motion. Development of suitable devices which will operate below 10^{-9} torr is essential. None of the precision potentiometers or transducers, using the sliding wire principle, operate satisfactorily below 10^{-9} torr. Magnetic or reluctance type transducers are limited by the outgassing of insulation materials.

5.0 Requirement for XHV Instrumentation

5.1 Density Sensors - Instrumentation for the 10^{-12} torr range under cryogenic conditions is not presently available. Existing tubulated gauges will require modification of the envelope and signal pickup to retain accuracy and sensitivity for measurement in the test volume.

5.2 Detection of Gas Species - Development of mass spectroscopic or spectrographic sensors is required for the measurement and discrimination of individual gas species in the test chamber with particular attention to the location of the sensor in the guard vacuum and its effect on the gauging device and its maintenance.

5.3 Development of Directional Mass Spectroscope - to determine the origin and composition of gases within the test volume.

5.4 Means for Calibration - of pressure and density sensors for instrumentation below 10^{-10} torr are currently unavailable.

5.5 Temperature Sensors - Instrumentation for the measurement of gas temperature within the experimental volume during cold soak and solar irradiation must be developed.

6.0 Development of Miscellaneous Accessories

6.1 Optical Windows - The only acceptable method for visual observation within the XHV systems now consists of fused "Housekeeper-type" windows, which are available only in relatively small sizes. Because these seals involve the use of fusing techniques and high temperatures in the manufacturing process, they are not optically flat. The development of suitable gasketing techniques which would allow the use of optically flat elements within the wide temperature range of the cryogenic system is needed.

7.0 Development of Monitors for the Leak Detection

7.1 Fabrication Leak Testing - Development of methods and instruments, for leak testing during fabrication of critical components, field assembly and start-up, suitable for 10^{-12} torr service must be evolved.

7.2 Routine Leak Testing - Development of a sensitive method for the "buttoning-up" and leak testing prior to each test run, providing sufficient sensitivity to detect very small leaks, prohibitive to the attainment of the desired vacuum levels, is required.

8.0 Vacuum Characteristics

8.1 General - Many of the subjects pertaining to this study in the area of ultra high vacuum technology relating to materials and chamber construction have been extensively studied and are described in other reports. The most applicable document, originally prepared for Arnold Engineering Development Center, United States Air Force, is Space Chamber Study, Contract AF 40(600)-952, Phase I - Technical Report, Section II & III. In light of the performance levels required for Chamber D, certain areas are re-examined below.

8.2 Adsorption and Desorption - In recent years, the achievement of pressures in the XHV range, has gradually become possible in increasing volumes. This accomplishment is based on very careful and often ingenious experimental techniques, developed from the better understanding of the physical processes, which are dominant at these pressures.

Examination of the basic principles, which apply to evacuation of a closed vessel originally filled with atmospheric gas constituents shows that severe changes in gas fluid mechanics take place, as the density within the chamber decreases. Initial removal of gas molecules from the enclosed chamber, by the vacuum pumps, represents considerable mass flow, which is supplied primarily by gas molecules in the gas phase. The collisions between gas molecules are in the concept of classical kinetic gas theory and are the controlling factor.

Until 99.9999% of the initial molecules are removed, at 10^{-3} torr, the behavior of the gas fluid in manifolds, fittings, and pumps follows the laws of turbulent or laminar flow. The gas compression work, which reaches a peak near 0.5 atm rapidly decreases to insignificant values. Between 10^{-3} torr and 10^{-4} torr, two very significant changes occur.

1. The fluid flow becomes Knudsonian free molecular flow, controlled by collisions of gas with the conduit walls rather than among gas molecules.

2. There are more molecules attached in a monomolecular layer by adsorption forces to the wall, than there are molecules left as a true gas in the chamber.

From Table XVI-1, it is evident that, when the pressure is further reduced, the removal of molecules from containment surfaces becomes the cardinal problem of attainment of UHV.

The success of extending the operating technique into the XHV region is possible only if the role of the adsorption and corollary desorption is fully taken into account. Fig. XVI-1 also indicates, that operational pressures cannot be established instantaneously by an increase of the volumetric pumping capacity, but that they become established as time dependent equilibrium conditions occuring when the depletion rate of the molecular layer on the containment walls or internal structures becomes equal to the number of molecules removed from the system.

Considering the total inventory of molecules in an XHV system, it is realized, that for operation in the UHV and XHV range, no leaks can be tolerated. At 10^{-10} torr, the total number of molecules in the gas phase represents at atmospheric pressure, a volume of less than one millionth of a milliliter, (6.6×10^{-7} cc). The experience in intermediate sized UHV chambers and small XHV chambers confirms the above discussion.

The time of pumpdown to 10^{-3} torr can be predicted by evaluation of the volumetric relations of the chamber and available pumping speed. Until recently, pumpdown time to pressure below 10^{-3} torr was considered unpredictable. However, the work of Redhead, Beecher, and Rosenzweig [1] indicated that careful evaluation of the adsorption and desorption mechanism, as a function of adsorption energy provides a basis for rational approach to pumpdown times, at least in a qualitative way. This method has been used for the estimation of equilibrium pressures in a large UHV facility.

The results of this study provide a rational illustration of problems and a guidance to assess the problems of Chamber D.

By calculating the desorption rates for various temperatures and progressive depletion of the original monomolecular layer, using Polanyi equation, Redhead [2] derived the times necessary to achieve pressure levels at which the capability of the pump equals the rate of depletion from the sorbed layer. His model consisted of a volume of 1 liter of 100 cm^2 surface connected to a pumping device having a speed of 1 lit/sec. Because the inventory of molecules in the volume as gas is insignificant at very low pressures, these figures approximate within the accuracy of this calculation, pumpdown times of general validity for UHV chambers, which have a pumping capability of approximately 9.3 lit/sec for each sq ft of internal surface. Curves in

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[1] References are assembled in Section XVI-8

Table XVI-1 were computed for the surface temperature at or near room temperatures and on Fig. XVI-2 for bakeout temperature of 597°K. The comparison of these two results clearly indicates the necessity of using as high a bakeout temperature as feasible within material and structural design limits. Further work by Beecher and Rosenzweig fully confirmed Redhead's calculations and the remarkable benefit of the lowering of wall temperatures after bakeout illustrated on the Fig. XVI-3.

From a study of Figs. XVI-1, XVI-2 and XVI-3, it is evident that the most important species of molecules affecting the time and equilibrium pressures are those characterized at room temperatures by adsorption bond energies of 20 to 40 Kcal/mole.

Experiments on outgassing of metallic surfaces at the National Research Corporation Space Vacuum Laboratory indicate that water vapor has this range of adsorption bond energy and is the most significant molecular species seriously limiting the attainment of very low pressures in a short time. The beneficial effect of bakeout at elevated temperatures can drastically improve the situation.

The roughness of the surfaces increases the effective surface of the containment vessel and the volume of the gas desorbing from the walls. If the material undergoes reversible or irreversible oxidation or hydration, the effective adsorption surface can increase by orders of magnitude. Therefore, it is necessary to limit consideration of construction materials for the Chamber D to highly polished materials of low oxidation characteristics or those producing an impermeable and stable, strongly-bonded layer of oxides or hydrides. The degree of perfection of this film must be very high and no porosity can be tolerated.

Molecules, which are strongly bonded, are insignificant for the achievement of XHV. Thus it is possible that selection of construction materials, which have very high bond energies, such as refractory materials, may offer significant advantages over presently preferred metals. The improvement by using exotic materials such as titanium zirconium, etc., is however, by far exceeded by the benefit gained from reduction of the temperature. Fig. XVI-3 illustrates the very great improvement in the equilibrium pressure which can be realized by only a small reduction of containment vessel temperature, from room temperature to 250°K (-23°C). Chilling to cryogenic temperatures will produce much more drastic improvements in equilibrium pressures.

For the present study, these calculations are significant in establishing the feasibility of the concept. Mathematical treatment of the considered

system during the design phase, using the actual geometry, more precise thermodynamic data, a better knowledge of physical constants at considered temperature levels can establish a rational engineering basis for Chamber D.

8.3 Outgassing - In addition to gases adsorbed on their surfaces metals also have quantities of gases dissolved within them. Typically, a standard cubic centimeter of dissolved gases is present in each cubic centimeter of metal. These gases include hydrogen, nitrogen, and inert gases. Some of these gases, notably hydrogen are free to move by diffusion within the metal structure. When a metal is subjected to vacuum, the dissolved gases are removed from the surface and the equilibrium condition is shifted, so that a concentration gradient is set up. The gas gradually diffuses from the metal bulk into the vacuum where it is pumped away.

At room temperature, the outgassing from a metal surface due to diffusion is initially several orders of magnitude less than that due to desorption of surface gases, being approximately in the range of 10^{-10} torr lit/sec/ cm^2 after a few hours. However, after several hundred hours of pumping or after a bakeout which strips away most of the adsorbed gases, this diffusion component is the principal factor in outgassing. Hydrogen is, by several orders of magnitude, the most mobile of the dissolved gases and thus forms almost all of this diffusion outgassing load.

The rate of outgassing due to diffusion from an unbaked metal is dependent upon time and metal temperature, varying in time approximately as $t^{-1/2}$ and with temperature as shown on Fig. XVI-4. Baking a metal to remove adsorbed gases, increases diffusion rates as well, thus speeding up removal of dissolved gases, and may, if carried long enough, deplete the metal of dissolved gas to a point where the outgassing rate drops sharply off at about t^{-2} time dependency.

This effect is shown on Fig. XVI-5 for stainless steel. For aluminum, this "starvation point" cannot be reached within reasonable times.

If metals are cooled, after long bakeouts, their outgassing rates are still temperature dependent, being controlled by the diffusion constant. However, these rates can be considered independent of time because, by bakeout, a point of gas depletion has been reached which, at room temperature, would take hundreds or thousands of hours. At this point, changes occur very slowly, consequently, outgassing curves for well backed out metals can be plotted against temperature alone, Fig. XVI-6. This chart is based on calculation, however, some experimental points are shown.

Metal outgassing rates, even at room temperature, can easily be reduced to about 10^{-13} torr lit/sec / cm^2 by bakeout, whereas rates far lower can be produced by lowering the temperature of the metal. What does this say about the limiting effects of outgassing on attainable vacuum? A well trapped diffusion pump can pump at least 1 lit/sec of hydrogen for each cm^2 of pumping duct opening into a vacuum space. It will pump more than this amount from regions nearer the pump itself, namely, the trap and pump duct surfaces. At a pressure of 10^{-12} torr, each square centimeter of pump duct opening can counterbalance 10 cm^2 of a surface outgassing at a rate of 10^{-13} lit/sec cm^2. If the outgassing rate is reduced to 10^{-14} by further bakeout or chilling the walls, 100 cm^2 can be maintained for each square centimeter of duct opening, and so on.

A chamber surface 10 to 100 times the pump duct area betokens a very practical working volume, and one can conclude the following:

1. For an ultimate pressure of 10^{-10} torr, it is sufficient to bakeout the container walls and allow them to cool to room temperature.

2. For an ultimate pressure of 10^{-12} torr, it is advisable to refrigerate walls after bakeout, however, longer bakeouts (several days) may suffice.

8.4 Leakage - Gas loads imposed by leakage can become quite serious when extremely low pressures are attempted. Considering a trapped pump with a net speed for air of about 0.5 lit/sec / cm^2 of duct area for nitrogen (equivalent to about 1.0 lit/sec for hydrogen) and an ultimate pressure of 10^{-12} torr, one could tolerate an inleakage of about 0.5×10^{-12} torr lit/sec if no other gas sources were present. This leakage is equivalent to about 0.65×10^{-12} atm cm^3/sec per square centimeter of pump throat area. For a 6 ft by 6 ft system having an area of about 2×10^5 cm^2 one might expect to have a pump throat area of 2×10^3 cm^2 from the foregoing discussion. The maximum tolerable inleakage of air would therefore be about 1.3×10^{-9} atm cm^3/ sec. Detecting this total leakage in a chamber of such size is at present at the limit of detector capability, and locating individual contributory leaks is well beyond the detection art at the moment. At 10^{-10} torr, the tolerable leakage is higher by two orders of magnitude, if one wishes to assign all pumping speed to leaks. If one wishes to assign 10 percent of the pumping speed to leaks then 1.3×10^{-8} atm cm^3/sec. total leakage is tolerable. This amount can probably be detected with a helium sensitive mass spectrometer.

Undoubtedly, the best way to avoid the problem of leakage in going to lower pressures is to employ a two walled shell, with a guard vacuum at approximately 10^{-5} torr in the interspace. As can be seen from Fig. XVI-7, the guard vacuum will drastically reduce the significance of small porosities or leaks compared to a single-walled shell. Since the inner shell may not need to carry atmospheric loading, it can be made lighter. This approach also reduces the mass of metal to be heated for bakeout and, if the inner chamber is to be chilled, the interspace vacuum provides thermal insulation. Although there may still be single-walled portions of the chamber at the pumps, the area of potential leakage is greatly limited and will allow detection sufficiently precise to enable attainment of XHV range.

The following conclusions can be drawn with reference to leakage:

1. To attain 10^{-10} torr to 10^{-11} torr, a single wall vessel may be sufficient.

2. To attain 10^{-12} torr, a double wall vessel is desirable, perhaps mandatory.

8.5 Seals and Sealants (Static)

8.5.1 General - Providing impermeable seals at large openings between removable covers and the test chamber proper is very difficult if operating pressures below the conventional vacuum levels of 10^{-6} torr are to be achieved.

At the densities corresponding to XHV pressures, the number of molecules pumped through the available pumping ports and by condensation on cryogenic condensing surfaces is very limited. Thus, the evaluation of seals and sealants is an important requirement.

8.5.2 Review of Available Techniques and Materials - The study of sealants and seals for UHV application has been systematically carried out by several investigators since 1958.[3, 4, 5]

The basic purpose of a seal is to reduce the number of atmospheric molecules which can enter the test vacuum between the mating surfaces of the flanges. A continuous area offering very high impedance to the passage of these molecules must be established around the complete periphery of the joint, in order to fulfill this function. Fusion of metal between the separable flanges would provide the highest impedance but would impair the later use of the flanges. The gas load through the

flanges with this type seal would be limited to gas diffusing through the fused metal and through weld imperfections. However, the accessibility to the test article would be limited by the requirement for grinding off the weld and hence the chamber would be suitable only for long term tests. (This does not comply with the NASA design guidelines for Chamber D.)

The use of a highly viscous grease or wax to fill the microscopic voids between the flanges to prevent the flow of gas molecules through the joint is a technique often used in the conventional vacuum regimes. Even the best greases are not acceptable for use in the UHV range and their use is limited to pressures of the order of 10^{-3} torr to 10^{-4} torr. Their contributions to the gas loads, entering the UHV space, consist not only of vapors of the grease but also of dissolved or absorbed molecules of water, atmospheric gases, and other materials.

The amount of these dissolved and absorbed molecules at UHV and XHV densitites represents a very large, practically inexhaustable reservoir of gases, which are released into the test vacuum over very long periods of time. Therefore, the first requirement for UHV technique is to abstain from the use of grease and to adopt white room techniques of cleanliness.

If viscous liquids cannot be used, it is essential to provide a capillary channel with very high impedance to the passage of molecules around the periphery of the seal, closing as nearly as possible the opening between the mating surfaces of the flanges.

This can be done in two ways:

1. By making the capillary passage very long and narrow

2. By reducing the effective gap between narrow contact surfaces by the use of gaskets, which conform closely to the macroscopic irregularities of the flanged surfaces by elastic or plastic deformation.

The lapped flange is a practical version of the capillary type seal. A major problem with this type flange results from the necessity to maintain close flatness tolerances over relatively large areas. A seal, from atmospheric densities to UHV, cannot be accomplished by the use of a single barrier. However, the high impedance of a lapped flange in the molecular region, and the absence of additional gas loads, makes this type of a seal attractive as a barrier between a "guard vacuum" and UHV region. For these reasons it it often the only approach which can be used in the ultimate XHV regions.

Joints or flanges, which use gaskets, require considerably less perfection in the flatness and finish of the mating surfaces.

The use of elastomers, in the form of "O-rings" or gaskets, is the most practical method for achieving very tight joints and is practiculariy valuable, where repeated opening of the joint is essential for operation of the facility. Two basic limitations are inherent in this type of joint:

1. The additional gas load from the elastomer enters the UHV area and increases the density within the experimental chamber.

2. The service temperature of such joints is limited by the physical properties of the elastomer.

The gas load contribution from the elastomer consists of a) gases which permeate through the molecular structure of the elastomer and b) released gases and vapors that are originally diffused within the elastomer. Careful choice of elastomers is necessary to insure low gas load contributions, and at the same time to provide the degree of elasticity which is needed to permit the surface of the gasket to completely close those spaces between the asperities of the metal flanges.

Laboratory investigations of sealant materials prove that commerical types of silicones are unsuitable for UHV service in spite of very low outgassing rates. Similarily, natural rubber is not suitable. Synthetic rubbers such as butyl and nitrile are more suitable. Fluorinated polymers of the "Vitron" type are better than other materials at room temperatures, however, the ultimate vacuum which can be obtained with these gaskets is limited to the 10^{-9} torr to 10^{-10} torr range, since outgassing and permeation of gases through even the best elastomer remains rather high at room temperatures. Intensive studies of the outgassing of various materials and their diffusion rates have been completed recently.[6] It becomes evident that the influx of molecules from even the best elastomers at room temperatures cannot be handled by the maximum possible pumping means within the UHV range.

Careful mechanical designs, which limit the exposed surface of the sealing elastomer, and the use of double "O" rings with intermediate pumping can reduce the gas load substantially. The most effective reduction of the diffusion and permeation rate however, can be achieved by lowering the gasket temperatures. It has been demonstrated on a medium size chamber that the gas contribution from elastomeric seals can be reduced by several order of magnitude and pressures in the low 10^{-10} torr range achieved by chilling the elastomers to sub-zero

temperatures, even if the chamber walls remain near room temperature. Considerable work was done by the National Bureau of Standards on the use of elastomers for sealing of joints at cryogenic temperatures.[7,8] It was proved, that even though the elastomers become brittle at temperatures around -100°C, and though their shrinkage is greater than that of the confining metal flanges, it is possible to establish tight joints if the compounds are carefully selected and the gasket highly compressed by proper groove confinement and heavy bolt loadings. The volumetric pre-compression requires internal hydraulic loadings of several thousand pounds per sq inch, if the joints are to be tight at low cryogenic temperatures. Testing of these joints was carried out under conventional vacuum requirements. The use of elastomers at cryogenic temperatures however, remains an open question and further work is required to evaluate the leakage rate for UHV applications.

The second large group of seals uses gaskets, which conform to the irregularity of the flanges by plastic deformation. Such materials are either inert polymeric plastics such as Teflon, polyetheline, polyvinyl chloride, of "dead-soft" metals. The dead soft metals provide the great advantage of reducing the additional gas load and have a range of temperatures far exceeding thatof the polymers and elastomers. Very successful applications were made of "O" rings of fine gold, "dead-soft" copper, flat gaskets of the "sheared" design by Alpert, and various forms of "crush rings" of soft iron. The use of soft aluminum foil "pinched" between tapered flanges by Batzer proved successful for UHV design. Common problems with these metallic gaskets are:

1. The relaxation of the initial loading, as a result of differential thermal expansion between the flanges, bolts, and the gasket materials during temperature cyclings and work hardening of the gasket material during bolting.

2. Temperature cycling on large flanges.

While the metallic flanges offer the lowest additional gas load and the widest operating range of temperatures, which can allow bakeout at elevated temperatures, the mechanical design requirements are very critical. The bolt loading required to accomplish the necessary plastic deformation and yielding of the gasket material is very high.

Flexing and rotation of the flanges, with these high bolt loads, must be prevented to preclude opening of the joint as a result of differential thermal expansion. Some successful designs use highly loaded bolts

which are preloaded by intentional rotation of the flanges, or by the bending of specially contoured flanges. Careful mechanical design of the flange, the bolting, the gasket, and the loading devices is most important and must be proved for the full temperature range of the operating and bakeout cycle. It is quite common to have metal gaskets remain tight during elevated temperature bakeout only to leak when cooled to the normal service temperature.

The lapped capillary seal and the elastomer type seals have the operating advantages of reusability and short closing times. Metallic seals, in which the gasket material is plastically deformed, are not re-usable and require replacement of the seal every time the chamber is opened. Cleaning of flanges to remove the remnants of metallic wires or gaskets is frequently required before a new gasket can be installed since considerable cold welding or adhesion occurs between the gasket material and the flanges at high bakeout temperatures coupled with exposure to UHV environment. The time required for accomplishing this cleanup must be provided when scheduling tests in which vehicles or mechanisms cannot withstand the high temperatures of the initial bakeout. Pressure levels below 10^{-9} torr can be attained in chambers after exposure to the atmosphere when opened for installation of the test specimen after the initial bakeout. Short loading times (10 to 20 minutes) and dehumidified air assist in re-establishing the vacuum.

8.5.3 Conclusions

a. Sealing of the guard vacuum from the atmosphere can be accomplished by conventional elastomeric seals.

b. Double "O" ring or square section seals, with provision for cooling during bakeout (to prevent overheating of the elastomer) and during operation of the vacuum chamber (for the reduction of gas permeation and diffusion) is a promising sealing means but should be evaluated to determine the gas contribution to the system. The selection of the elastomer, the configuration of the confining groove, and the area of the elastomer exposed to the vacuum are important evaluation parameter.

c. The uniformity of preloading and the control of flange deflection around the sealed periphery are important aspects of the engineering evaluation of designs.

d. An effective seal of the liquid nitrogen shrouded experimental volume can be achieved either by lapped capillary flanges, elastomer sealed flanges of flanges of metal gasket design.

e. Capillary type seals must be of simple configuration with provisions for maintaining the flatness of the mating surfaces.

f. Specified designs must be carefully evaluated from the aspects of temperature cycling and alignment to preclude opening of the capillary passages. The conductance of a parallel plane channel increases as the square of the capillary clearance; thus thermal stresses and excessive structural restraints can result in detrimental warping or deformation.

g. Since complete liquid nitrogen shielding of the experimental volume is essential, the seal between the guard vacuum and the test vacuum must either be designed for surfaces at cryogenic temperature or heated to prevent embrittlement of the elastomer. This can be achieved by maintaining a temperature of the flange at or above 220°K (- 53°C).

h. The high preloading, and required means for distribution of this load without deflection or rotation of the flanges under loadings on the elastomer, up to 5000 psi, will require exacting design and careful development of heavy profiles to maintain full loading throughout the temperature range from bakeout to the service temperature of approximately 100°K.

i. For metallic gaskets, the design of the flange must maintain the pressure load on the sealing element throughout the full service range from room temperature to full bakeout temperature and cooldown to service at 100°K. The expediency of the loading and unloading, which will necessitate scraping of flanges and installation of new metallic gaskets must be evaluated in the test schedules, particularly if testing of devices or test articles which cannot stand the bakeout temperature is contemplated.

8.6 <u>Backstreaming and Oil Migration</u> - Without employment of any auxiliary devices, most modern diffusion pumps have oil backstreaming rates less than 0.05 mg/cm^2/min as measured directly at the pump inlet. This backstreaming is associated with the formation of boundary layers inside the vapor nozzle of the top pump stage. Cooled shields, surrounding the top nozzle cold-cap, which remove the diffused portion of the vapor jet, reduce the backstreaming rate by a factor of 50 to 100 without reducing the pumping speed. Thus, a 32 inch pump with a cold-cap backstreams the same amount as a 4 inch pump without the cold-cap.

Recent experiments have shown, that even with the cold-cap, the backstreaming still originates from the vicinity of the top jet cap(or the edges of the cold cap) and that it occurs in well defined straight line pattern. Objects placed in a chamber directly above the diffusion pump produce clear shadows on the wall. The area behind the objects does not have any noticeable oil films, even though an adjacent surface is completely covered with a heavy layer of oil. Such observations have been carried out in 90° elbow ducts, where the line of demarcation between wet and dry surface has not advanced after a year of continuous operation. Measurements have also shown that, at a distance from the pump inlet equivalent to the pump diameter, the backstreaming rate is reduced by about 95 percent.

Thus, in modern diffusion pumps, the backstreaming has been reduced to a point where the stream is so rarefied, that there are essentially no inter-collisions and it can be easily condensed by water cooled baffles which intercept all "optical" paths between the pump and the chamber.

However, it is important to distinguish between primary backstreaming and oil migration. Since the condensed pump fluid has a finite vapor pressure, its migration into the chamber must be arrested by refrigerated baffles or molecular sieve traps. Efficient baffles at liquid nitrogen temperature, for example, will reduce the vapor pressure of the pumping fluid to a completely insignificant level.

To achieve this stable pumping, fluids and efficient diffusion pump boiler designs should be used which do not produce excessive thermal cracking. Diffusion pumps of recent design have significantly improved heat transfer conditions in the boiler and employ efficient jet assemblies. Further, they operate without using highly superheated vapor. Thus, they are not prone to thermal oil cracking and do not produce volatile oil fractions which are difficult to trap over a long period of time.

It has been shown by several experimenters that contamination of a chamber by migration of diffusion pump fluid can be reduced by proper trapping, to the point where the partial pressure of fluid or its condensible fractions is undetectable with a mass spectrometer having a 10^{-12} torr threshold. These results have been obtained in systems employing organic pumping fluids and liquid nitrogen cooled and adsorbent traps. The trapping properties of the systems have been demonstrated to remain essentially unchanged over many months of continuous operation.

From existing experience the following conclusions can be drawn:

1. Backstreaming and oil migration are not limiting factors in Chambers "blanking-off" at 1×10^{-10} torr.

2. Backstreaming and oil migration may be a limiting factor but are not a preventive factor in "blanking-off" chambers at 1×10^{-12} torr pressure levels.

9.0 Pumping Systems for Ultra High Vacuum -

9.1 General - Various pumping means are available which can evacuate suitably designed chambers to pressures of 10^{-10} torr and below.

a. Diffusion Pumps - Diffusion pumps employing either organic fluids or mercury have been widely used, combined with adequate trapping, to prevent backstreaming and migration of the motive fluid. Their advantages are:

1. Economy
2. Ability to pump all gases equally well.
3. High hydrogen pumping capacity (up to twice the air capacity).

Venema[9] and Mark[10] have used mercury diffusion pumps for pressures as low as 10^{-12} torr. The advantages of mercury are the stability of fluid and the ease of trapping it completely with liquid nitrogen traps. Pressures well below 10^{-10} torr have been reported by Power[11] and Metcalfe[12], and they have been produced at NRC, utilizing diffusion pumps with organic fluids and liquid nitrogen or zeolite trapping. Pressures below 10^{-9} torr can be produced without trapping whatsoever, but backstreaming fluid will enter the chamber. At the present time, there is no conclusive evidence that diffusion pumps utilizing organic fluids can achieve a pressure below 10^{-12} torr, since they decompose to some extent, and their decomposition products may possibly not be condensible on nitrogen cooled surfaces to the necessary low vapor pressure. The use of diffusion pumps, however, makes very good sense for 10^{-10} torr to 10^{-11} torr systems, particularly large ones, where their economic advantages are outstanding.

b. Molecular Drag Pumps - Molecular drag pumps of the Becker[13] type are presently available commercially. They have been confined to small sizes, since they are essentially high speed

8000 - 15,000 rpm, multi-stage axial compressors. They are not very suitable for application on metal systems, since they have low compression ratios for hydrogen.

c. Gettering Pumps - Gettering has been used to reduce the pressures of systems to 10^{-9} torr and below, after they have been pumped to levels close to this range by diffusion pumps. Holland [14] and Caswell [15] have described firing of getters to achieve pressures in the 10^{-9} torr range.

Perhaps the most powerful use of gettering has been made by Clausing [16] who evaporated titanium onto liquid nitrogen cooled surfaces. Gettering is primarily a supplement to other forms of pumping and is applicable only in cases where a static condition prevails, or where the pressure is sufficiently low (10^{-9} and below) so that the getter does not quickly saturate with a monolayer. In cases where a test object is included in the chamber, there may be mechanical difficulties in directing the evaporation of the gettering material.

d. Electronic Vacuum Pump - Pumps which ionize gas and then trap it by electric or magnetic fields have been extensively employed to achieve pressures as low as 10^{-12} torr. The most common form of this pump is the ion gauge itself. Both heated filament and cold cathode types have been used. These are understandably of little use in large systems, but cold cathode discharge pumps, in which sputtering of the cathode material continually provides chemically active chemisorption surfaces have been developed in sizes up to 5000 lit/sec. Since there is no motive fluid, there is no backstreaming and no necessity for trapping. However, these pumps are limited by re-emission of pumped gases, which is particularly severe when inert gases are pumped. They are, nevertheless, useful for 10^{-10} torr systems and perhaps below, particularly for metal systems in which hydrogen is the principal gas evolved. They are more advantageous on smaller systems, becoming inordinately expensive for larger pumping speeds when compared with diffusion pumps. A typical price comparison of fully trapped diffusion pumps against sputter ion pumps is shown below:

Net Pumping Speed (Liters/Sec.)	Cost ($) Diffusion Pump and Traps (1)	Sputter Ion Pump and Power Supplies (2)
20,000	15,500	90,780
2,400	4,800	12,900
1,000	2,500	7,900

1. Based on net speed after trapping for diffusion pumps.

2. Based on 1/3 of rated power supplied for ion pumps.

e. Cryogenic Pumping - Several systems employing cryogenic pumping for operation at 10^{-10} torr and below have been built. These systems have used cryogens with boiling points lower than liquid nitrogen, usually liquid helium or hydrogen. Cryogenic pumping, like gettering, is used as an adjunct to diffusion or ionic pumping, to extend the pressure range. Mark has attained 10^{-10} torr in a 3 inch diameter by 10 inch long chamber, which is actually the inner shell of a 6 wall dewar, by refrigerating this shell with liquid helium after sputter-ion pumping it to the 10^{-7} torr range. Caswell [15] and Berndt [17] have used liquid helium cooled fingers, to aid in pumping chambers into the low 10^{-10} range, while Redhead and Hobson [18] have used immersion in liquid helium, as a means of bringing small glass systems to 10^{-12} torr and below.

An examination of typical vapor pressure curves [19] shows that, by condensation alone, all elements except hydrogen and helium can be reduced below 10^{-12} torr, while hydrogen can be reduced to the 10^{-7} torr range. By reducing the temperature to $3^{\circ}K$, hydrogen can be reduced to below 10^{-12} torr, leaving helium as the residual gas.

Although little research has been done, one can conjecture that helium may be abosrbed on surfaces at $3^{\circ}K$. Redhead and Hobson concluded that baked glass at $4.2^{\circ}K$ strongly absorbs helium and it is possible that clean metals and other sorbents would as well. In any case, a surface area in the chamber at 3 to $4.2^{\circ}K$ would reduce the load on a diffusion pump substantially.

It can be concluded from the foregoing that:

1. Both sputter-ion and trapped diffusion pumps permit attainment of 10^{-10} torr, with diffusion pumps presenting the more economical choice, particularly for large pumping speeds. Other auxiliary methods are available but probably only to augment the main elements.

2. For pressures of 10^{-12} torr, ion and diffusion pumps may have to be augmented by cryosorption and gettering pumping mechanisms. It has not been definitely established that either trapped diffusion pumps with organic fluids or sputter ion pumps are of material aid in the 10^{-12} torr range, although diffusion pumps employing mercury have been successfully used.

10.0 <u>Ultra High Vacuum Instrumentation</u> - Desired operating conditions of Chamber D in the pressure range of 10^{-10} torr are,in the terms of vacuum technology,in the range of XHV. This range is at the present time the frontier of technology. However, the successful development of the ultrahigh vacuum field, which can be considered as a region of pressures between 10-8 and 10^{-10} torr, was mastered so well in recent years, that engineering perfection and better understanding of the inherent vacuum and surface physics makes further progress in the XHV region realistic within a short future.

Prior to 1950, the art of vacuum technology considered 10^{-8} torr as an ultimate low pressure. Experimental results, in spite of many attempts by ingenious and careful experimenters, seemed to fail in producing further improvement. Nottingham [20] presented evidence that the vacuum gauge, which was used, was not capable of indicated pressures below 10^{-8} torr as a result of photoemission by soft x-rays generated by electrodes of the conventional ionization gauge. In 1950 Bayard and Alpert [21] developed an improved high vacuum ionization gauge, which considered the Nottingham analysis and by clever rearrangement of electrodes, reduced the x-ray limit by several orders of magnitude. The use of this gauge proved that pressures, which could be achieved in small glass systems by very careful techniques, existed already, but could not be measured until the Bayard-Alpert (B-A) gauge was perfected. This emphasized the importance of gauging for the progress of vacuum technology. As a result of consistent and systematic efforts, gauging techniques progressed by development of the improved version of the B-A gauge by 2 to 3 orders of magnitude.[22,23] Meanwhile, another method of ionization using assistance of magnetic fields to increase the efficiency of ionization, developed by Redhead and Hobson,proved to have a linear response down to 10^{-12} torr. Lafferty [24] improved the hot filament ionization gauge by application of a magnetic field, which increased the ionization efficiency so much that the x-ray limit was lowered to an equivalent of pressure reading of 10^{-14} torr.

The art of pressure measurement is available down to the XHV pressure range. However, at pressures in the region of 10^{-8} torr to 10^{-10} torr and lower, the composition of gases, which constitute the XHV molecule content, is far from resembling the composition of original atmospheric constituents. Gases released from the walls by desorption or permeation and by diffusion from the solid solution in the metals are hydrogen, carbon monoxide, fragments of water molecules and many light hydrocarbons, often as atomic species or free radicals. In the presence of plasma, the population of the test volume includes plasma, ions and electrons. The rates of ionization and capabilities of charge neutralization on the sampling electrodes of ionization gauges widely vary for the above "gas" population. The very meaning of the "pressure", defined as a mechanical force exerted on the unit of gas containment area by molecules in random motion with thermal velocities following the Maxwellian distribution, hardly applies within a simulating space with walls at temperatures close to the space sink, the test object surface near room temperature, and in the presence of a large solar radiation input. It is obvious that according to Knudsen, considerable deviations will exist in molecular motion and affect the momentum exchange at collisions with the walls. Because one of the most important aspects of space simulation is the effect of interactions of surface with residual molecules or ions on vehicle surface and their effect on tribophysics of moving devices, it becomes obvious that, for the definition of the experimental conditions, a better knowledge of the constituents by species, ionization or exitation degree and their vectors of thermal energies becomes essential. This requires identification by extremely sensitive mass spectrometers, which should be able to measure partial pressures, in the molecular population, equivalent to 10^{-14} torr. Also, the need to measure the degree of ionization and exitation within the molecular population and the vectorial quality and quantity of molecular motion will be ultimately needed. To classical mass spectrography, which has been brought to a remarkable perfection and which can detect, in a Diatron-type detector, partial pressures down to 10^{-12} torr, was recently added the double focusing mass spectrograph which, theoretically, should improve the resolution rather than the absolute sensitivity. The principle of a cyclotron was developed for very low partial pressure measurements in the Omegatron.[26] The limits of these spectrographs are of a similar order of magnitude and are in excess of the total pressures which are equivalent to the XHV range. However, these mass spectrographs remain the work horses of leak detection. Very recently, a significant step forward was accomplished by the use of a multistage electronmultiplier, which is used as an ion detector. By using this high gain electronmultiplier, instead of the [27] simple collector, the sensitivity and resolution was remarkably increased. The sensitivity, at room temperatures, is claimed to be in the order of 10^{-13} torr and by chilling the multiplier to liquid nitrogen temperature, the dark current is so reduced that the potential sensitivity to 10^{-17} torr is claimed in several references.

It can be summarized that the present status of pressure measurement and discrimination of partial pressures for constituents of XHV chambers is available, as basic principles. However, the development of sensors which can be located within the cryogenic shrouds of a chamber such as Chamber D, will need considerable development effort to accommodate the sensors, deflection magnets, ion detectors, preamplifiers and/or multipliers within the geometry of the test chamber. Maintenance and reliability for these components, which are not physically accessible during long-term tests, is another problem which must be solved by specific development tailored to the particular geometry and test program.

11.0 Cryogenics

11.1 Heat Sink and Cryopump - It is the intent of Chamber D to approach as closely as possible the environment of space. Such an environment should continuously absorb radiant energy and material coming from the test speciment. In order to reduce the number of molecules reflected back to the test article before they can be condensed or pumped, it is desirable to have the heat sink also act as the cryopumping surface

The main leak from a test article is likely to be trapped air. The main constituent of air, nitrogen, has a vapor pressure of 10^{-11} torr at 20°K, the cryopumping panel temperature in Chamber A. To insure adequate condensing coefficients, a temperature somewhat lower should be used. A liquid helium system would provide a cryopump surface of approximately 5°K which would be adequate to condense all leak gases except helium, hydrogen, and neon which must be removed by the diffusion pumps. To insure sufficient area for these molecules to pass through the heat sink, a chevron type design should be used.

Considering the temperature levels required (5°K operation and 475°K bakeout), the size of the chamber, porosity of the surface, and the maintenance required to keep the surface in an acceptable condition, it appears that 304 stainless steel should be used for the heat sink.

The ability of the heat sink to absorb radiation like a black body will depend on the emissivity of the surface viewed from the test specimen. At the present time, the various methods of obtaining high emissivities (anodizing and painting) will not hold up while outbaking at high vacuum levels. Various organizations are investigating better methods of treating surfaces and an answer to this problem may be forthcoming in the near future. A chevron design would help to increase the emissivity of the array.

11.2 Thermal Shield - In order to reduce the heat load on the heat sink refrigeration system from the ambient environment, a thermal shield should be inserted between the helium panels and the chamber wall. The liquid nitrogen refrigeration system used for Chambers A and B would provide a convenient temperature level for this thermal shield. For a vacuum system composed of a main vacuum chamber and a guard vacuum chamber, a logical arrangement is to have the guard vacuum shell also serve as a thermal shield.

11.3 Thermal Loads - The liquid helium system must be designed to handle the thermal loads indicated below:

Thermal Loads for Liquid Helium in Chamber D (KW)

Source	
Heat Leak	
Radiant	.2
Conduction	.2
Vehicle	.5
Solar Simulator	1.7
Line Loss	.3
Total	2.9 KW

11.4 System Concepts - The chevron design of the heat sink cryopump can take the form of long sections of "V" shaped cross-section or short "V" shaped fins mounted on long tubes. The former will be less expensive, easier to maintain and check, and hence is preferred. The thermal shield must be a vacuum vessel and is best cooled by coiling tubing around the outside of the shield, see Fig. XVI-10 for simplified outline of Chamber "D".

Outbaking can be accomplished by using infrared lamps, electric strip heaters, and circulating gases. Strip heaters add a source for outgassing and increase the number of penetrations required, Infrared lamps also increase the penetrations and require additional space in the chamber. Recirculating hot gases that normally flow through panels appears to be the best method to outbake the chamber.

11.5 Liquid Helium System - Because of the small temperature rise available with liquid helium and its low specific heat, a two-phase system should be used. This system should be designed for peak loads to avoid the difficulties of storing liquid helium. A typical schematic of the system is shown in Fig. VIII-1 at the end of Section VIII.

11.6 Economic Analysis - Capital and operating costs for a liquid helium system are compared in the following table on a purchase and lease basis. This analysis was based on an assumed load of 1.5 KW, an early estimate of the load for Chamber D that was revised by later calculations. To minimize line losses, this refrigerator must be located immediately adjacent to Chamber D.

Liquid Helium Refrigeration 1.5 KW - 5°K

	Purchased	Leased
Capital Investment	$ 500,000	$ 0
Annual Operating Costs		
Plant Operation	97,000	97,000
Make-Up	91,500	91,500
Lease Charge	0	145,000
Total	$ 188,500	$ 333,500

12.0 Solar Simulation

12.1 General - Various methods of simulating solar radiation, discussed in Section VII, were evaluated for application in Chamber D. The requirements for spectral simulator and collimation lead directly to a preferred concept based on Xenon lamps mounted outside the chamber. A description of the conceptual design of this system appears in Section IV of Volume III. Two design concepts of the optical system for admitting radiation into Chamber D were developed.

In the first system (Fig. XVI-8), the lamp array on top projects radiation down to a small aperture and onto a mosaic lens assembly. This mosaic lens assembly projects uniform radiation onto an intermediate lens and then onto a liquid helium cooled cellular window. The intermediate lens is a cooled cellular pseudo Fresnel lens. The intermediate lens serves as the window to the liuqid nitrogen cooled shroud. This lens would be cooled by radiation to the liquid nitrogen shroud. The liquid helium cooled cellular window would serve as the window to the liquid helium shroud. Here again the quartz segments would be cooled by radiation, It is intended that the cellular frame conduct the heat absorbed by the window away to the liquid helium cooled perimeter. Since it is extremely difficult to obtain thermal contact of the quartz segments to the cellular frame, the quartz will be cooled by radiation to the cellular frame. It is not the purpose of the liquid helium to cool the cellular window to assist in the cryogenic

pumping, but merely to prevent the quartz segments and cellular frame from radiating into the test volume due to their own temperature when the solar simulator is on. The large pseudo Fresnel lens would be very expensive.

The second system is essentially the same optically but with a different lens configuration (Fig. XVI-9). In this system, the intermediate lens is a solid piece of quartz mounted in a gold-wire vacuum seal. It prevents molecular diffusion from the guard vacuum region to the inside of the LN_2 shroud and also prevents radiation from the window lens from impinging onto the liquid - helium cooled, cellular pseudo Fresnel lens. Similarly, the Fresnel lens prevents diffusion into the ultra-high vacuum region. This arrangement, furthermore, would be much cheaper than the previous one. For these reasons, the second system (Fig. XVI-9) is recommended.

13.0 Chamber Configuration Concept - A conceptual design of Chamber D (Fig. XVI-8) is based on a three-fold concentric arrangement of shells:

1. A barrier between atmospheric pressure and a guard vacuum operating at room temperature,

2. A barrier between the guard vacuum and a lower pressure region operating at liquid nitrogen temperature, and,

3. A liquid helium cooled vessel cryopump surface surrounding the test volume.

Extensive discussion of this concept is given in Volume III.

Shape and Orientation - The recommended conceptual design of a vertical cylinder for Chamber D is based on the following considerations:

1. Economy of construction

2. Ease of suspending the cryogenic vessel and the cryopump inside the outer shell with low thermal losses and accommodation of differential thermal movement.

3. Ease of sealing the joints between the body and head portions of the concentric vessels.

4. Ease of loading test articles and setting up tests, including instrumentation, prior to testing.

5. Ease of admitting the solar beam into the test volume.

6. Economy of space requirements for connection of diffusion pumping.

TABLE XVI-1

MOLECULAR INVENTORY AND IMPORTANT PARAMETERS IN A CHAMBER
(Approx. 6 ft by 6 ft diameter)

Pressure in Chamber	Molecular Density of Gas Phase at Room Temp. (mol / cm^3)	Impingement Rate by Gas Molecules at Wall (mol/cm^{2}sec)	Time to form a a Monolayer by Impinging Molecules on Wall (sec)	Molecules in Gas Phase	Molecules Adsorbed On Walls	Ratio of Molecules Absorbed on Wall to Gas Phase	Total Number of Molecules
Atmosphere 760 torr	2.5×10^{19}	2.9×10^{23}	1.7×10^{-9}	1.25×10^{26}	1 Monolayer - 10^{20} Molecules	8×10^{-7}	1.25×10^{26}
1 torr	3.3×10^{16}	3.8×10^{20}	1.3×10^{-6}	1.65×10^{23}		6×10^{-4}	1.65×10^{23}
10^{-3} torr	3.3×10^{13}	3.8×10^{17}	1.3×10^{-3}	1.65×10^{20}		0.6	2.65×10^{20}
10^{-6} torr	3.3×10^{10}	3.8×10^{14}	1.3	1.65×10^{17}		600	1.00×10^{20}
10^{-10} torr	3.3×10^{6}	3.8×10^{10}	3.6 hrs.	1.65×10^{13}		6×10^{6}	10^{20}
10^{-12} torr	3.3×10^{4}	3.8×10^{8}	15 days	1.65×10^{11}		6×10^{8}	10^{20}

3

14.0 Reference

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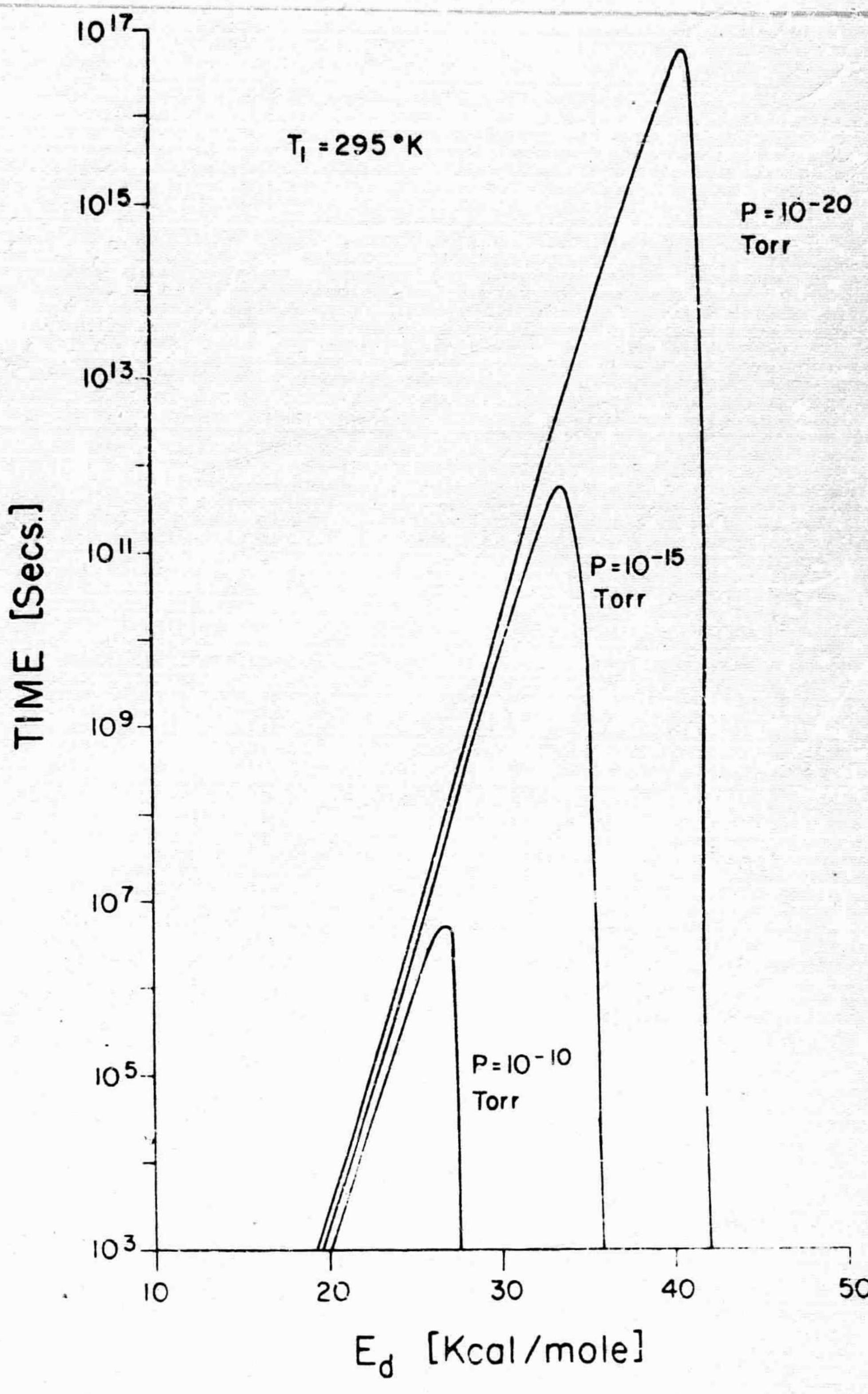
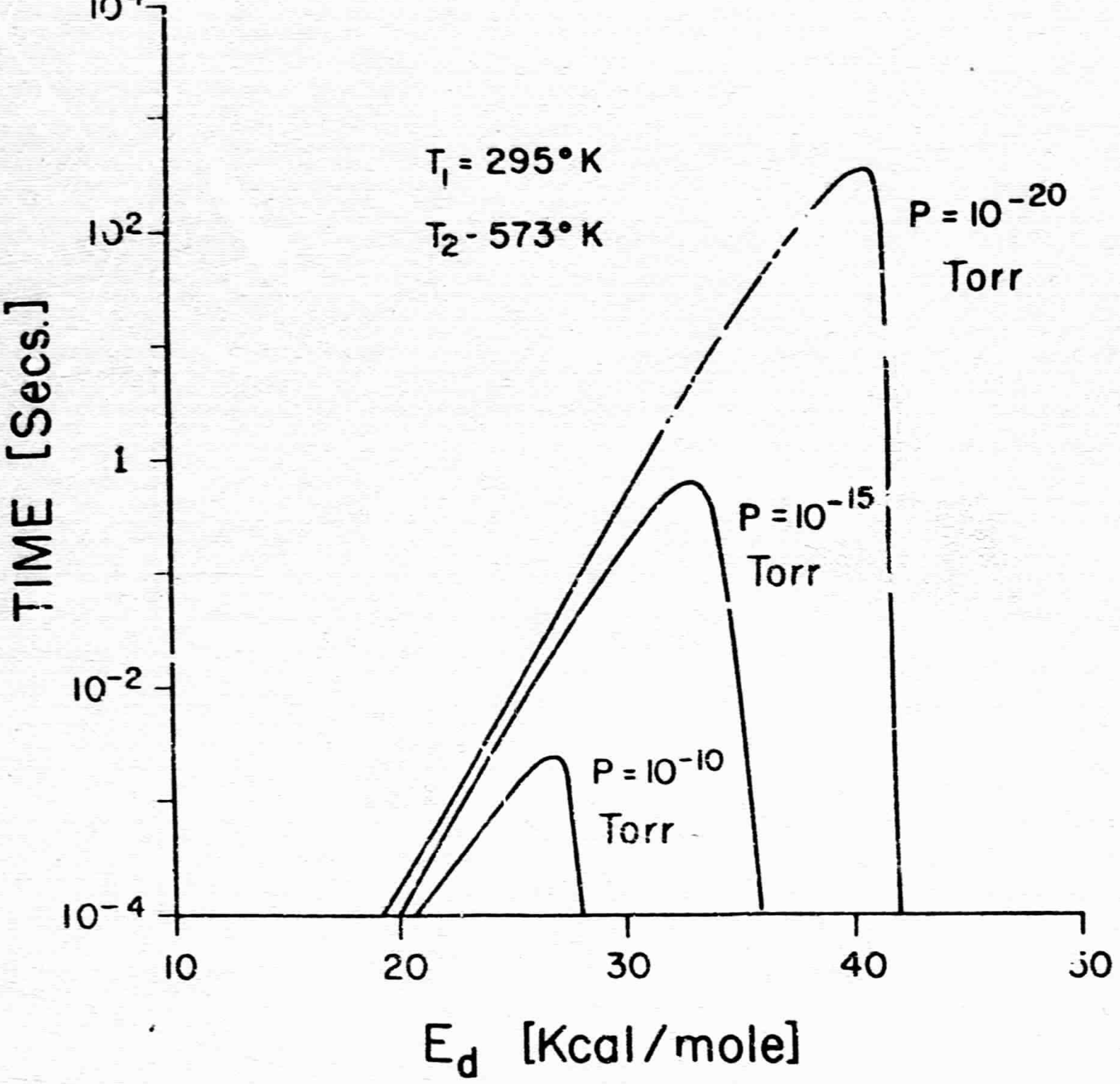


TIME REQUIRED TO REACH GIVEN PRESSURE AS FUNCTION OF ABSORPTION BOND ENERGY AT ROOM TEMPERATURE AND A PUMPING CAPACITY OF 9.3 L/SEC PER FT^2 OF CHAMBER AREA.

SOURCE: P.A. REDHEAD, J.P. HOBSON, E.V. KORNELSEN
ULTRA HIGH VACUUM

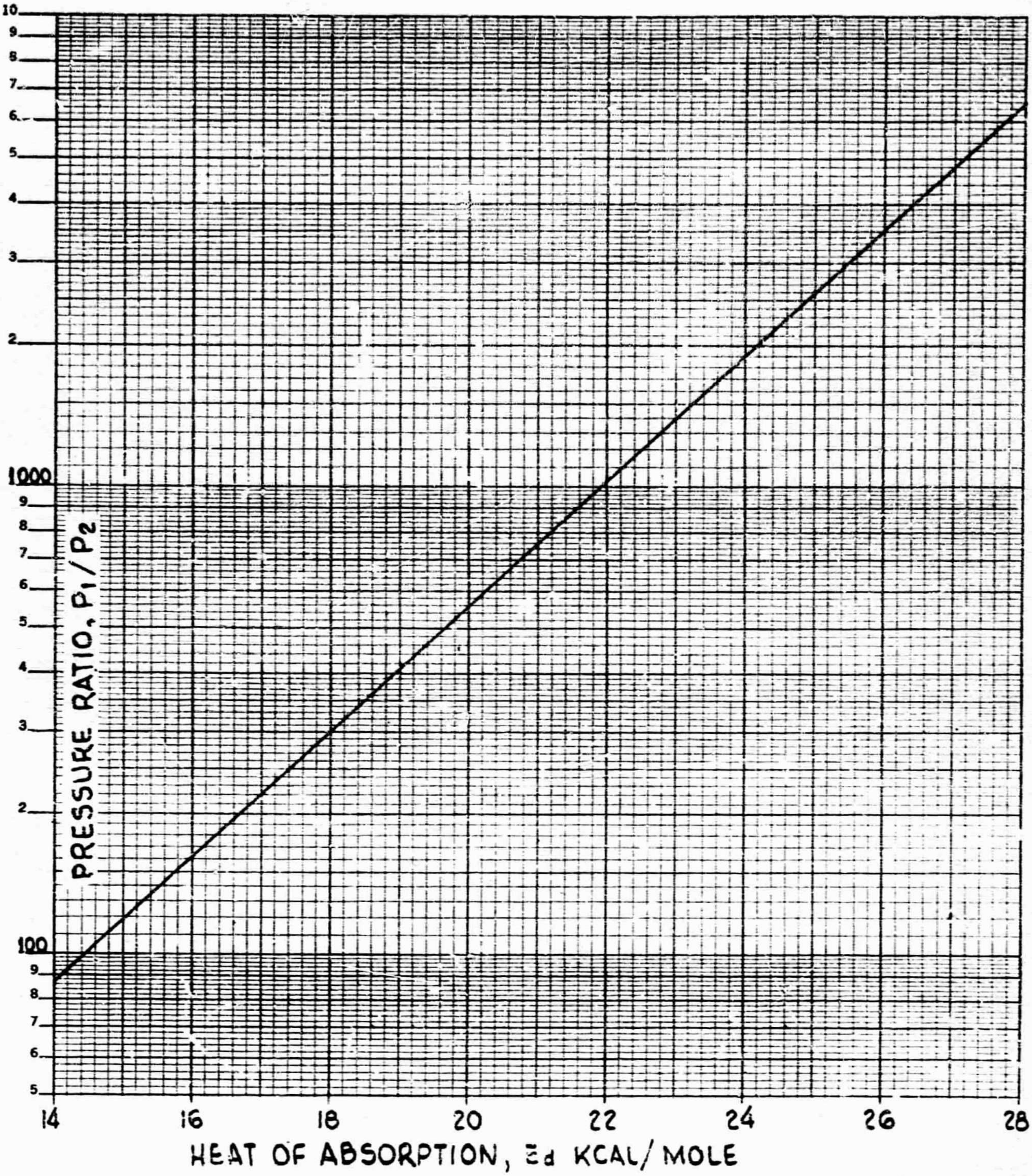
FIG. XVI-1



TIME REQUIRED TO REACH AN EQUILIBRIUM PRESSURE AS A FUNCTION OF ABSORPTION BOND ENERGY AND TIME FOR AN XHV CHAMBER AT A PUMPING CAPABILITY OF S/A 9.5 L/SEC PER FT^2 OF CHAMBER SURFACE DURING BAKEOUT AT 573°K.

SOURCE: P.A. REDHEAD, J.P. HOBSON, E.V. KORNELSEN ULTRA HIGH VACUUM

FIG. XVI-2



EFFECT OF LOWERING TEMPERATURE TO 250°K FROM 295°K

FIG. XVI-3

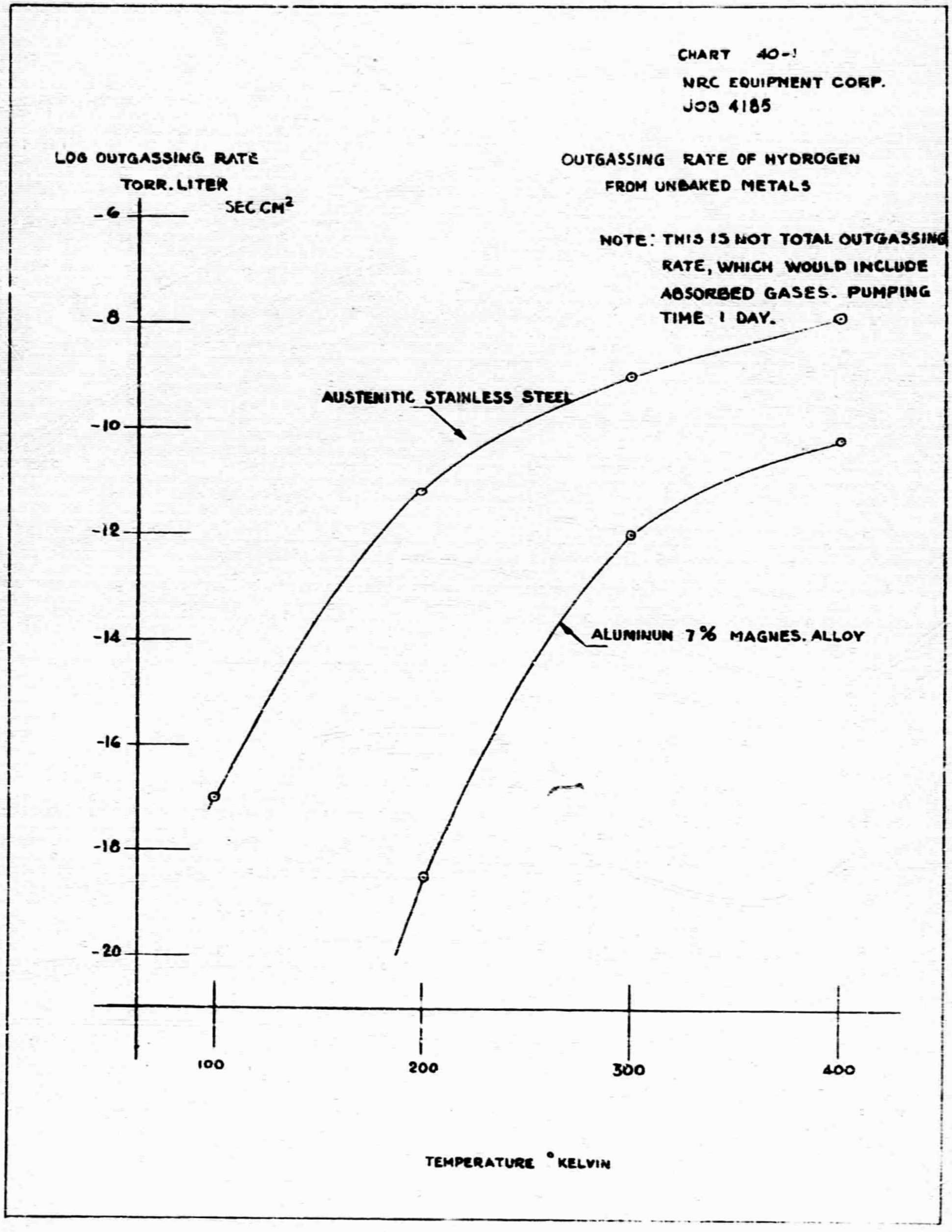


CHART 40-1
NRC EQUIPMENT CORP.
JOB 4185
LOG OUTGASSING RATE
TORR. LITER
SEC CM^2
OUTGASSING RATE OF HYDROGEN
FROM UNBAKED METALS
NOTE: THIS IS NOT TOTAL OUTGASSING RATE, WHICH WOULD INCLUDE ABSORBED GASES. PUMPING TIME 1 DAY.
-6
-8
-10
-12
-14
-16
-18
-20
AUSTENITIC STAINLESS STEEL
ALUMINUN 7% MAGNES. ALLOY
100
200
300
400
TEMPERATURE °KELVIN

FIG. XVI-4

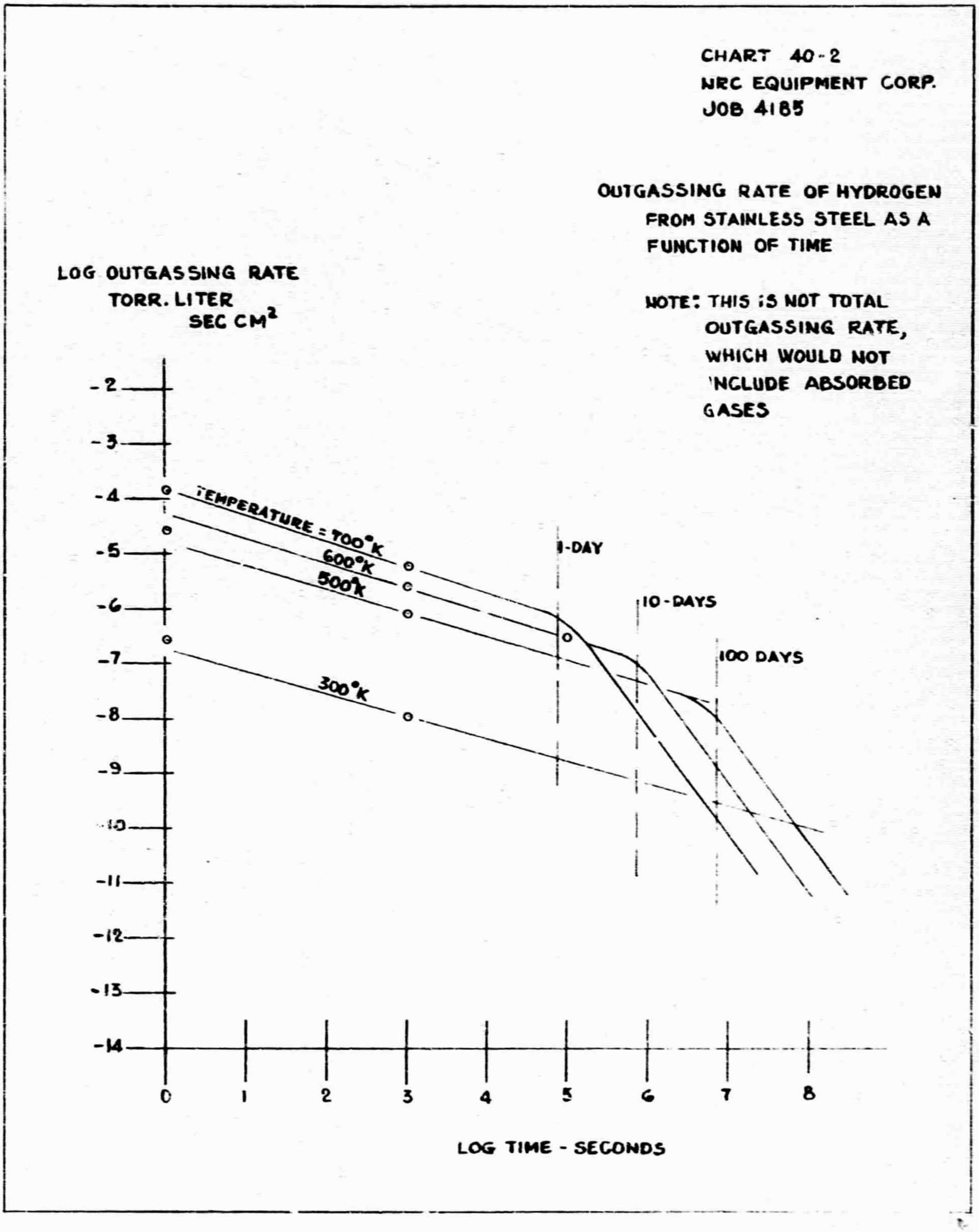


CHART 40-2
NRC EQUIPMENT CORP.
JOB 4185
OUTGASSING RATE OF HYDROGEN FROM STAINLESS STEEL AS A FUNCTION OF TIME
NOTE: THIS IS NOT TOTAL OUTGASSING RATE, WHICH WOULD NOT INCLUDE ABSORBED GASES
LOG OUTGASSING RATE
TORR. LITER
SEC CM²
-2
-3
-4
-5
-6
-7
-8
-9
-10
-11
-12
-13
-14
TEMPERATURE = 700°K
600°K
500°K
300°K
1-DAY
10-DAYS
100 DAYS
0
1
2
3
4
5
6
7
8
LOG TIME - SECONDS

II

FIG. XVI-5

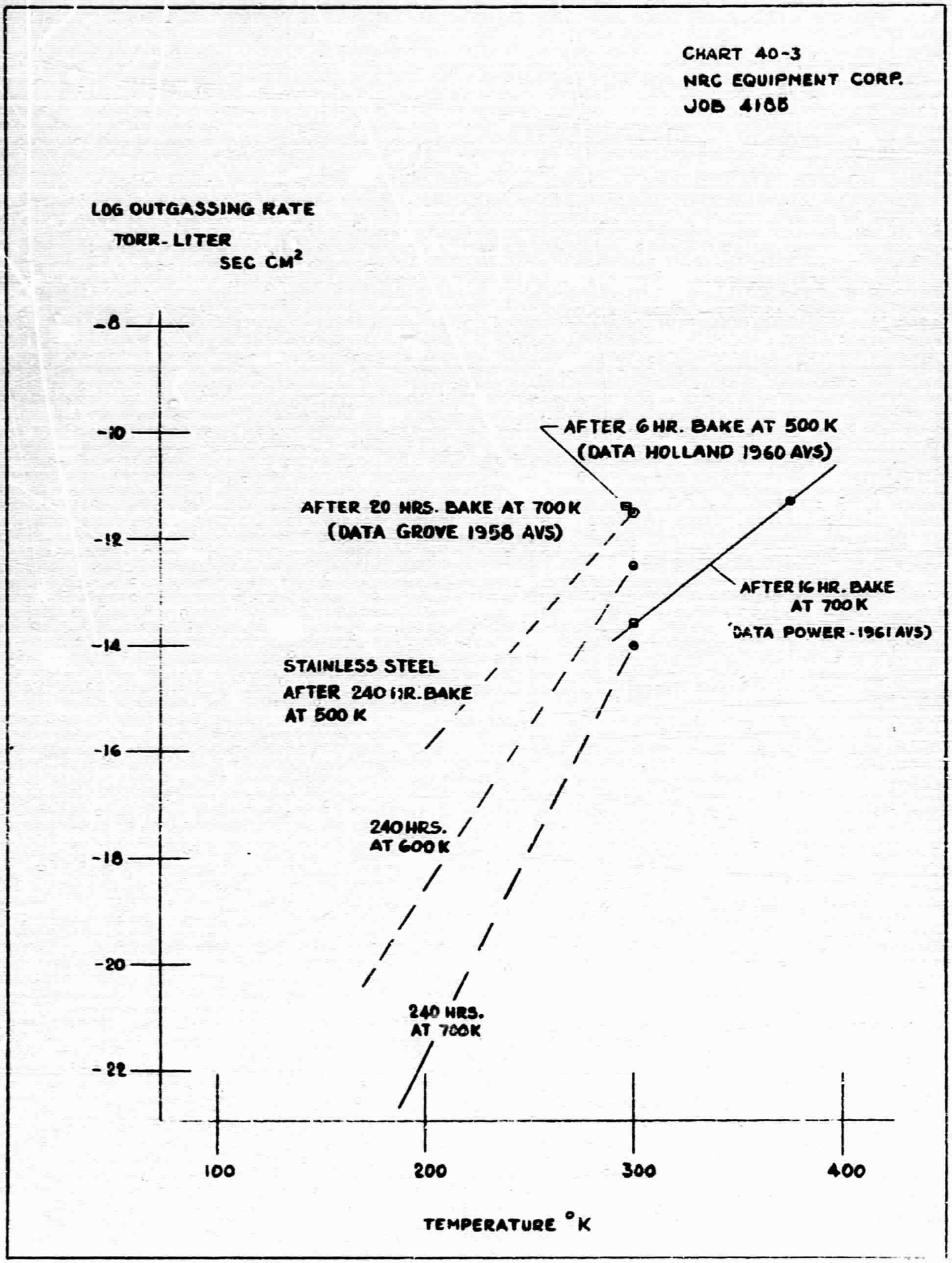
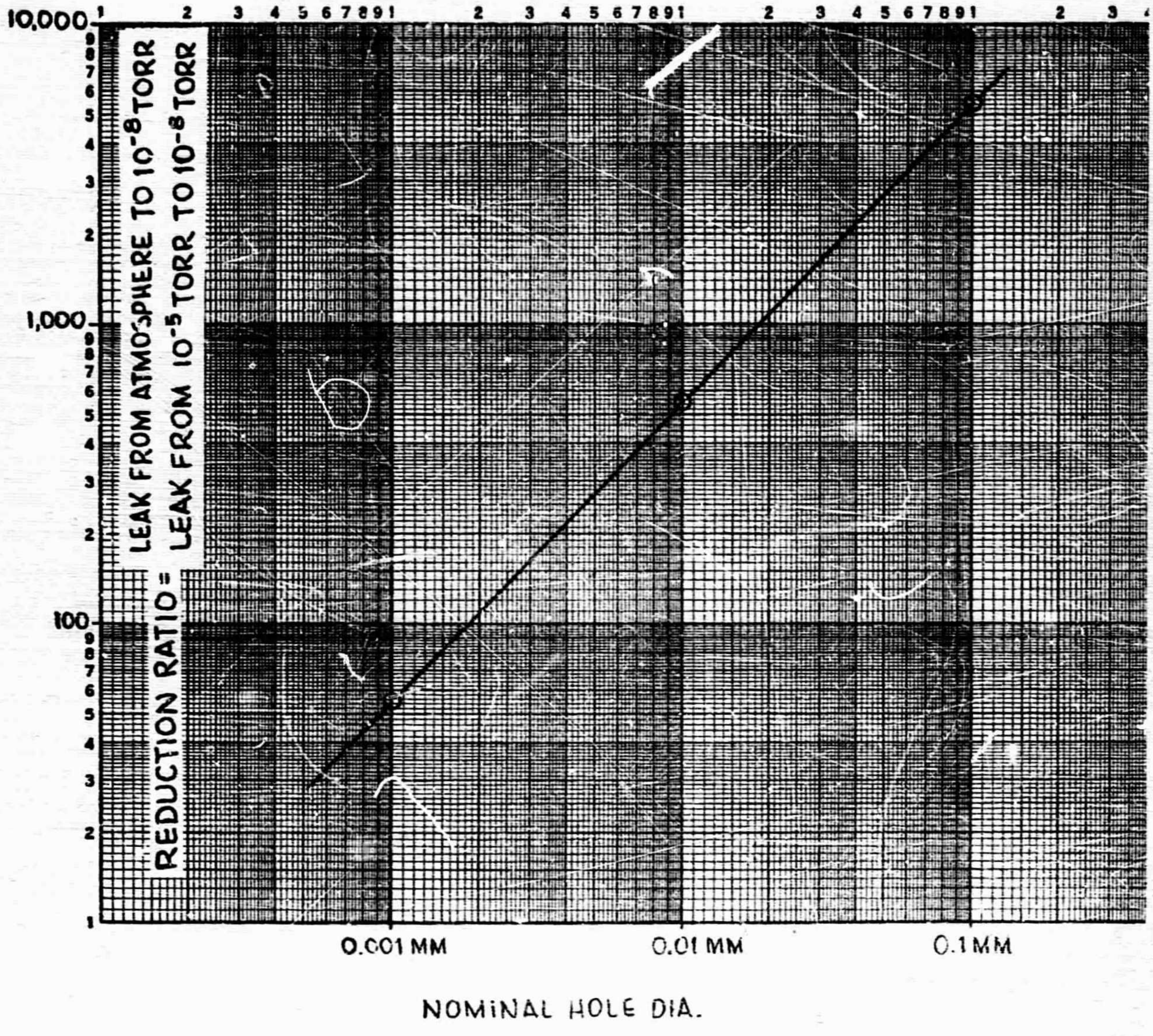


CHART 40-3
NRC EQUIPMENT CORP.
JOB 4188
LOG OUTGASSING RATE
TORR-LITER
SEC CM²
-8
-10
-12
-14
-16
-18
-20
-22
AFTER 6 HR. BAKE AT 500 K
(DATA HOLLAND 1960 AVS)
AFTER 20 HRS. BAKE AT 700 K
(DATA GROVE 1958 AVS)
AFTER 16 HR. BAKE
AT 700 K
(DATA POWER-1961 AVS)
STAINLESS STEEL
AFTER 240 HR. BAKE
AT 500 K
240 HRS.
AT 600 K
240 HRS.
AT 700K
100
200
300
400
TEMPERATURE °K

II

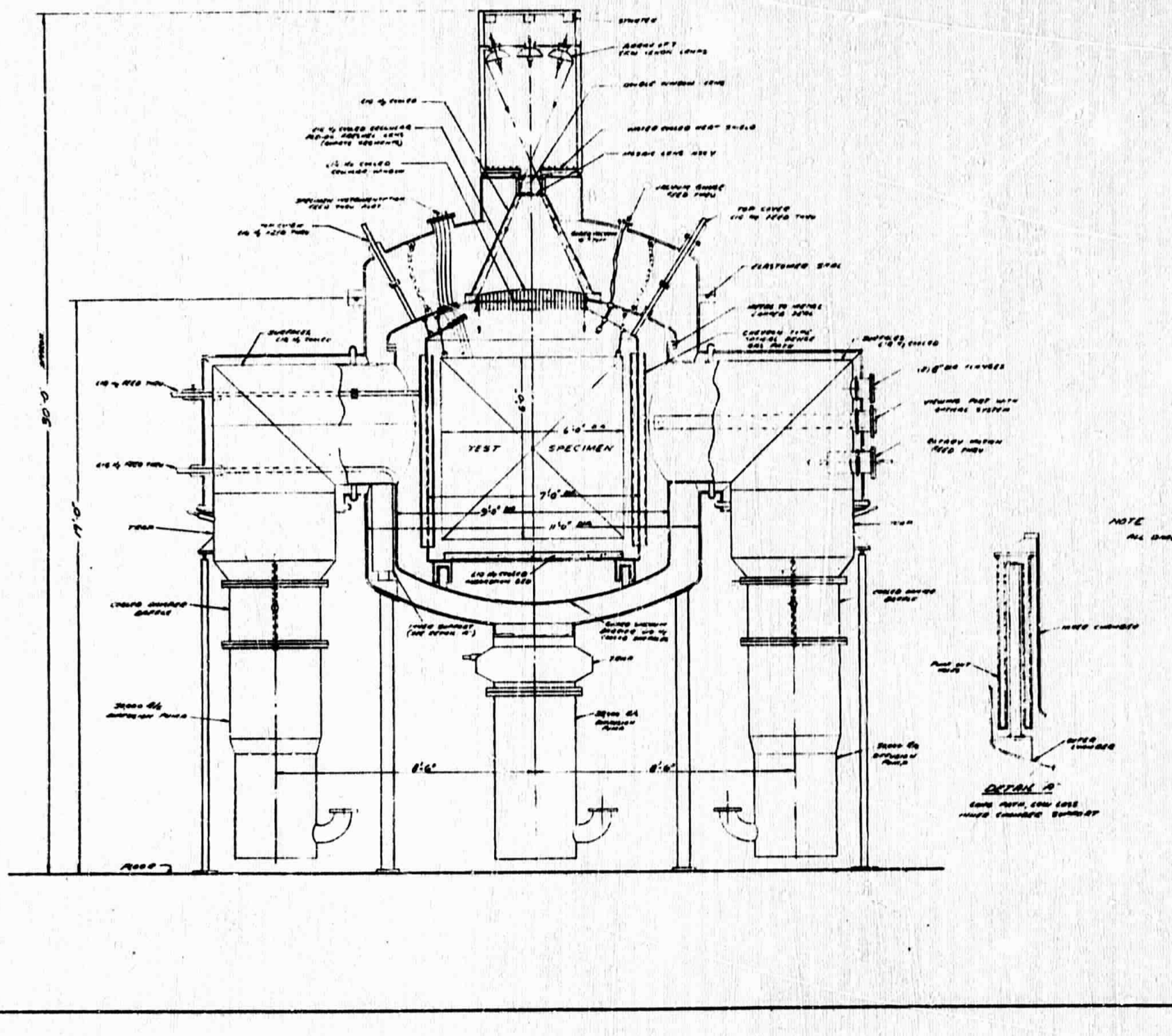
FIG. XVI-6



REDUCTION IN LEAKS THROUGH CAPILLARIES BY DOUBLE PUMPING

II

FIG. XVI - 7

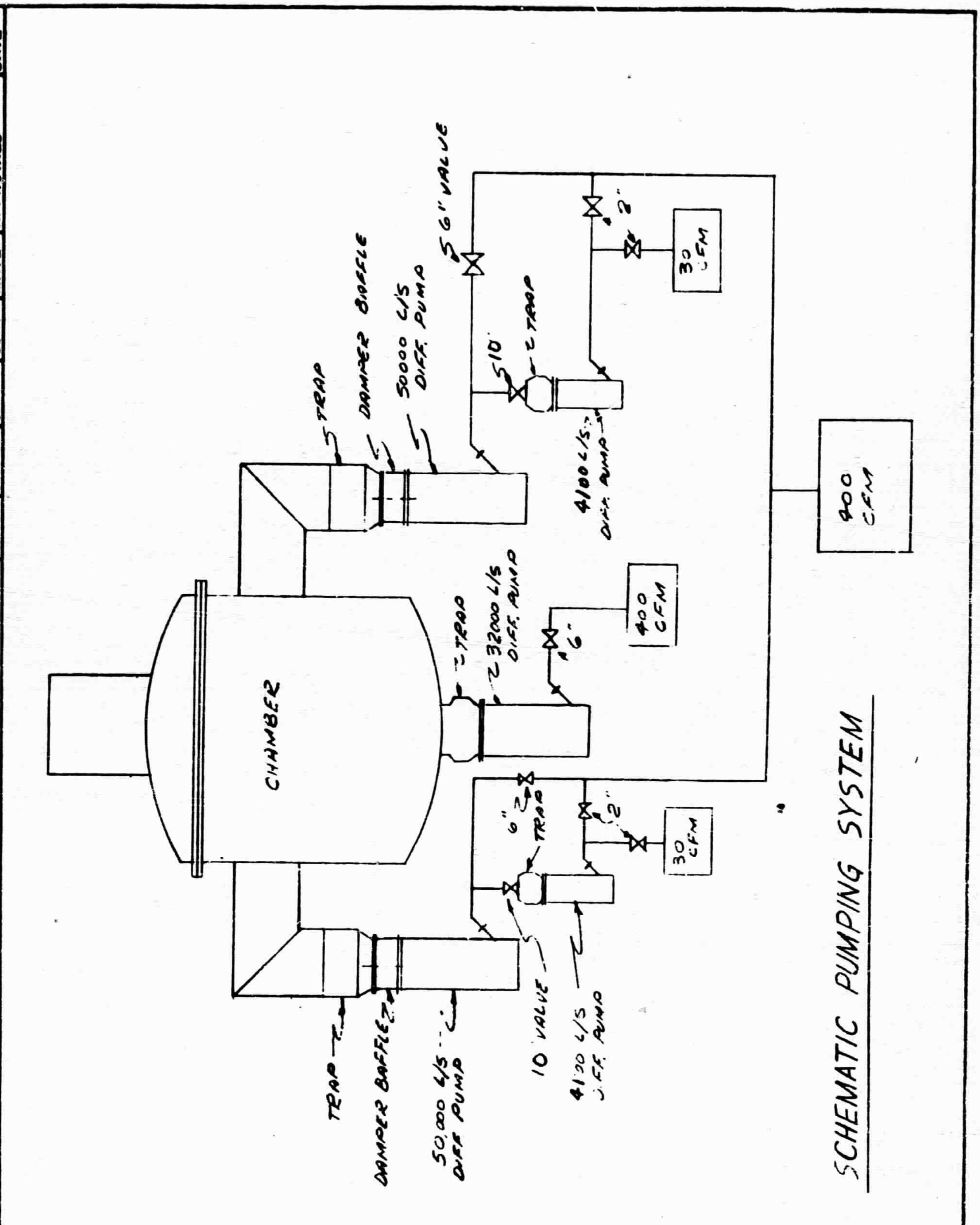


NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

CHAMBER D - SECTION

4185 FIG XVI-8

II



REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
0								

G-231-E 4-14-59 II	BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT N° NAS-9-419	JOB No 4185
		SCHEMATIC PUMPING SYSTEM	FIG. XVI - 9
			REV.

FOREWORD

This Volume III of a three volume report presents Design Criteria and Conceptual Designs of:

A. The Space Environment Simulation Chambers facility selected for construction, (Chamber A and B), and

B. A Space Chamber for Systems Tests under Extreme Vacuum, (Chamber D).

The report was prepared under Manned Spacecraft Center, NASA, Contract No. NAS 9-419 with Bechtel Corporation, in association with:

Air Products & Chemicals, Inc.	- Cryogenics
Bausch & Lomb, Inc.	- Radiation Simulation
Chicago Bridge & Iron Co.	- Chamber Vessels
FMC Corporation	- Special Mechanisms
General Electric Co. - MSVD	- Data Handling & Man Rating
National Research Corp.	- Vacuums

Volume I presents a summary description of the chambers facility selected for construction, the cost estimates, a project construction schedule, and recommended R. & D. Volume II presents some of the back-up studies conducted in support of the selection of facility characteristics for the conceptual design. Technical guidance was furnished by the Manned Spacecraft Center Working Committee on Space Environment Simulation Chambers.

Although Chamber D is not a part of the proposed facility, work on it was carried out in view of the expressed interest on the part of the Working Committee in the chamber's potential for later incorporation into the facility.

VOLUME III, PART A - DESIGN CRITERIA

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VOLUME III, PART A - DESIGN CRITERIA

CHAMBER D

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VOLUME III, PART B - CONCEPTUAL DESIGN

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DESIGN CRITERIA
Chamber A and B Complex

1.0 Purpose - In order to support the purpose and mission of the NASA Manned Spacecraft Center, it is necessary that facilities be provided for space environment simulation.

The following design criteria describe the design requirements of a Space Chamber Facility consisting of two space environment simulation chambers and their supporting facilities which will satisfy the following objectives within the limit of funds available:

a. Provide for simulated space environment testing of spacecraft configurations for the Apollo Spacecraft Program in modular and multi-modular assemblies.

b. Provide for developing and testing the capability of man to perform various operations and maneuvers inside and outside of the spacecraft in a simulated space environment and on a simulated lunar surface.

c. Provide for reliability testing of manned spacecraft designed for space travel and lunar surface landing by tests covering an extended period of time.

2.0 Chambers - The two space environment simulators covered by these criteria include:

a. Space and Lunar Surface Environment Simulation Chamber (Chamber A)- This chamber is required for simulation of vacuum, thermal, and solar radiation environments encountered in space flight and on the lunar surface to permit transient and steady state heat transfer studies and reliability tests to be made on complete spacecraft assemblies. It shall be sized to contain a vehicle as outlined in the criteria, and it shall be man-rated.

b. Space Chamber for Life Sciences and Astronaut Training Studies (Chamber B) - This chamber is required for simulation of vacuum, thermal, and solar radiation environments encountered in space flight and on the lunar surface for studies to be conducted on astronaut life support systems, and for training astronauts to accomplish space operations and lunar landings. It shall be sized to contain an Apollo command module, and it shall be man-rated.

3.0 Location of Facilities - The space chambers and supporting facility shall be located at the NASA - Manned Spacecraft Center, Clear Lake, Harris County, near Houston, Texas. The entire facility shall be integrated into the master site development plan on the area immediately south east of the Second Street and Avenue C intersection. The Manned Spacecraft Center is accessible by highway. Delivery of test articles by water in the future is contemplated. No railroad service is available to the Space Chamber Facility.

4.0 Scope of Design Criteria

4.1 General - The design criteria establish the requirements of a complete, integrated space environment simulation facility which shall include two space chambers, vacuum systems, solar radiation simulation equipment, cryogenic systesm (including liquid nitrogen reliquefaction and storage facilities), control systems, data handling and collection systems, enclosing buildings, offices, and other related structures.

The scope of engineering design effort required for the Space Environment Simulation Chamber Facility is generally illustrated by those structures, systems, capacities, and performance levels in the conceptual design of the Chamber A and B facility accompanying these criteria, except that in the engineering design it shall be assumed that responsibility of the Chamber Facility Architect-Engineer on the site improvements and systems integrated with the Manned Spacecraft Center shall extend only to the five foot line outside the chambers facility envelope, with design responsibility for those portions outside that line resting with others. Normal coordination of design features with the others carrying out design shall be a requirement on the Chamber Architect-Engineer.

Furniture and all other portable equipment shall be government furnished and is excluded from the scope of Architect-Engineer design.

While the design criteria present the requirements of a Space Chamber Facility as accurately and in as much detail as can be developed for a complex which is not yet designed, it is recognized that as the detail design develops some modifications in the technical design will be desirable. These modifications may affect dimensions, specific ratings, and equipment required. However, the scope of the facility described by these criteria and the performance capabilities which these criteria set forth shall not be compromised by modifications which may be necessary as the detailed design is developed.

4.2 Work Included - The Space Chamber Facility as defined above shall include the following basic equipment, systems, and structures:

a. Two space environment simulation chambers, and appurtenant man-locks.

b. Vacuum systems, including roughing and backing pumps.

c. Cryogenic systems including refrigeration plant and storage tanks.

d. Solar radiation simulators including cooling equipment.

e. Repressurization systems.

f. Control and Instrumentation.

g. Data Handling.

h. Cranes and hoists.

i. Chamber Building enclosing the chambers.

j. Facility Administration Building including control room, offices, and miscellaneous spaces.

k. Pump Building.

l. Cooling water towers and circulation systems.

m. Air conditioning equipment.

n. Electrical distribution system from 12.47 KV feeders.

o. Emergency power system.

4.3 Services Provided by Manned Spacecraft Center - The following services and utilities will be available from the Center:

a. Steam at 125 psig and approximately 500°F.

b. Chilled water at 39°F for air conditioning.

c. Potable, fire protection, and make up water.

d. Electrical power at 12.47 KV, 3 phase, 3 wire.

e. Telephone service.

f. Sanitary sewer.

g. Drainage, roads, and utilidors outside the five foot line.

5.0 General Technical Considerations - The two chambers and their supporting facilities shall be designed so as to obtain the maximum reliability and performance capability possible through the use of common or shared equipment. Critical systems may require standby units and in some cases capacity requirements may be met through the use of multiple partial capacity units. Wherever practicable and economical, provisions for upgrading of the performance capability, flexibility, and reliability of the chambers and their auxiliaries shall be included in the design as outlined in the criteria.

5.1 Design Life - The general facility shall be designed for a useful life of twenty years considering that normal maintenance will be furnished.

5.2 Man-Rating - The requirements for "man-rating" shall include provisions for breathing oxygen supply systems, methods of monitoring personnel activity and conditions within the chambers, an emergency standby power system for critical functions, a means of entering and leaving the chambers, and necessary safety and rescue systems. The chambers shall be designed to permit the following:

a. Test of spacecraft containing operating crew.

b. Ingress and egress from the outside of the chamber to the spacecraft during a test period.

c. The astronaut to leave the spacecraft, enter the space environment, and to perform useful work on the exterior of the spacecraft.

d. Manned entry from outside the space environment to perform necessary maintenance functions in the chamber.

5.3 Design Codes and Standards - The design of the facility and the equipment to be furnished shall be in accordance with the requirements of the applicable sections of the following codes and Technical Society Standards.

National Building Code	AIEE
ASA	NEMA
ASME - Pressure Vessel Codes	ASHVE
ASTM	NBFU
AISC	ASME

The chamber vessels shall be designed in general conformity with the ASME Unfired Pressure Vessel Codes except where deviations are justified by the design. A Code stamp will not be required for the vessels.

5.4 Incorporation into Masterplan - The general facility shall be integrated into the site development plan in the area southeast of 2nd Street and Avenue "C" intersection as shown on NASA Master Site Plan Drawing J-3.

Special features and the aesthetic appearance of the facility shall conform to and blend with those features as specified by the MSC Architects.

6.0 Facility Arrangement - The complex shall be arranged so that the Chamber Building will be the focal point with auxiliary buildings providing office space and equipment space for the supporting systems. The Chamber Building shall be arranged so that Chamber A is installed at the north end and Chamber B at the south end. Between the two chambers a spacecraft receiving and preparation area shall be provided.

The Refrigeration Plant shall be located as near as practicable north of the Chamber Building to minimize the length of cryogenic piping between Chamber A and the plant. Liquid nitrogen storage shall be located immediately west of the plant, the cooling tower area to the north of the plant.

A Pump Building shall be located on the west side of the Chamber Building adjacent to Chamber A.

A Facility Administration Building providing offices, biomedical rooms, and a control room shall be located adjacent to the Chamber Building on the east side.

7.0 Operational Features of Test Chambers

7.1 Chamber A

7.11 Operating Conditions

a. The chamber shall provide a simulated space environment for spacecraft up t 25 ft in diameter and 75 ft high with landing appendages up to 40 ft in diameter. It shall be capable of supporting a spacecraft weighing 100,000 pounds in a vertical position on a rotating platform and by suspension cables from the top of the chamber.

b. The chamber shall be designed for "man-rated" operations.

c. The chamber shall be designed for a design pressure level of 10^{-5} torr or better with a gas leak load of 27.6 torr lit/sec as specified in Section 8.1.5.

d. The chamber shall be capable of being pumped down to stable test conditions in 24 hours or less.

e. The chamber shall be lined with liquid nitrogen cooled heat sink walls at a working temperature of approximately $100^{\circ}K$.

f. A simulated lunar plane shall be provided. It shall operate at controlled temperatures ranging from $100^{\circ}K$ up to $400^{\circ}K$ as specified in Section 7 1.4.

g. Solar radiation and albedo simulation shall be provided. The solar simulation flux shall be controllable between 25 and 140 watts per square foot on a spacecraft located within the chamber as specified in Section 8.3. The simulators shall be located externally to the chamber.

h. The chamber and all of the supporting auxiliaries shall be designed to provide an uninterrupted test environment for a period of 30 days.

i. Provisions for future upgrading shall be as specified elsewhere in the design criteria.

7.1.2 General Arrangement of Chamber A - The space chamber shall be approximately 65 ft in diameter and 120 ft high with a hemispherical top and an ellipsoidal bottom head. A rotating lunar plane or turntable platform shall be provided in the lower portion of the chamber on which the spacecraft shall be supported. All of the interior walls above this platform shall be lined with heat sink panels. The chamber shall be so located with respect to the Chamber Building that the lunar plane platform shall not be higher than 4 ft above the main chamber floor elevation.

Working platforms around the internal periphery of the chamber shall be provided at two levels above the lunar plane (33 ft and 63 ft above the Chamber Building floor level) to provide access to the spacecraft.

Solar simulators shall be located on the top and side of the chamber and albedo simulators shall be provided on the side opposite the solar radiation simulators.

A 40 ft diameter door shall be provided for vehicle access. The bottom of the door shall be about one ft above the Chamber Building floor. Man locks shall be provided as outlined below.

7.1.3 Chamber Vessel - The chamber shall be approximately 65 ft in diameter and 67 ft high (straight shell) with a hemispherical head and an ellipsoidal $^{D}/3$ bottom head for a total height of about 120 ft.

It shall be fabricated of austenitic stainless steel plate. The interior surface shall be a clean mill finish. External stiffeners shall be fabricated of carbon steel.

The chamber vessel shall be designed for an external pressure of 14.7 psia.

Personnel access to Chamber A during testing shall be by a double manlock at the lunar plane level and by a single manlock at the platform level 33 ft above ground floor. Additional access during non-operative periods is through the 40 ft diameter vehicle entry door and by a door at a level 63 ft above ground floor which can be incorporated into a future manlock.

The double lock shall be composed essentially of two parallel single locks with an interconnecting door. The doors to the chamber and the interconnecting door shall be designed for full atmospheric pressure on each side while the exterior door shall be designed for full atmospheric pressure on the outside face. In addition, it shall have ports for observation into the locks, between locks, and into the chamber. The single lock shall contain two doors and ports for observation into the lock and into the chamber. The chamber doors shall be designed for full pressure on each side while the exterior doors shall be designed for full pressure on one side only. Each lock unit shall have a diffusion pump connection, three umbilical connections, and a nominal floor area 9 ft by 10 ft (capable of handling three men). Except for the chamber side doors of stainless steel, the locks shall be constructed of carbon steel.

The 40 ft diameter door for vehicle access to Chamber A should face an open floor area, and it shall swing out into this area. The test vehicle will be moved either by sections into the chamber and therein assembled or else moved into the chamber as a whole depending upon the size of the vehicle.

In addition to the chamber apertures mentioned above, there shall be four hatches in the top of the chamber to allow access for hoisting equipment. There also shall be openings in the chamber wall to attach diffusion and mechanical pump intakes, to admit solar and albedo light, and to admit repressurization piping. Penetrations shall also be provided for cryogenic piping, umbilical connections, and viewing ports.

Provisions shall be made for future upgrading of the chamber by allowing space around the solar simulators for future modules with necessary blanked off penetrations and also allowing space for installation of additional diffusion pumps.

All penetrations and openings in the chamber vessel shall be sealed in accordance with best "state of the art" practice for vessels operating in the range of 10^{-7} torr.

7.1.4 Lunar Plane and Turntable - Chamber A shall be provided with a Lunar Plane which shall be the surface of a rotary mount supporting the vehicle. The Lunar Plane shall provide varying temper- atures in the ranges of $100^{o}K$ to $130^{o}K$ and $300^{o}K$ to $400^{o}K$. The low temperature range shall be obtained with a liquid nitrogen cooled heat sink attached to the solid floor plate, and the high temperature range shall be obtained with electrical strip heaters. In operation the $400^{o}K$ may be attained and held for a maximum of 48 hours during a two week test time, or two hours during a 48 hour test time. The maximum test duration will be 30 days.

The rotary mount (turntable) shall be compatible with the chamber design so as to allow sufficient circumferential clearance for emergency repressurization gas flow. The turntable shall be approximately 45 ft in diameter, and it shall be capable of supporting a 100,000 pound test vehicle and rotating it in a vertical position. Clearances up to 40 ft shall be provided for landing appendages on vehicles 25 feet in diameter. It shall be assumed that the total vehicle weight may be concentrated on four landing appendages, with radii varying between 6.5 and 20 ft.

The turntable shall be rotated up to a maximum speed of 1-2/3 RPM, and the acceleration and deceleration shall be such as to not vibrate the vehicle under test. The turntable shall rotate $\pm 180^{o}$.

A prime mover shall be used to provide the power to the turntable drive. This prime mover shall be capable of operating in an environmental pressure from sea level to 10^{-6} torr and temperature ranges from $100^{o}K$ to $400^{o}K$.

If the prime mover and associated gear drive used cannot operate in the above temperature ranges, heaters and/or cooling coils shall be provided.

The lunar plane shall be solid plate fabricated in sections. The material shall be black anodized aluminum providing an emissivity above 0.9 on the upper side only. The lower side shall be chemically cleaned only. The heating cable and cooling tubes shall be installed on the underside prior to anodizing.

Liquid nitrogen and electrical power to the lunar platform shall be supplied through flexible lines suitable for rotation of the platform through $\pm 180^{o}$. Provisions shall be made in the rotary mount design so that a hard line instrumentation bundle and coaxial bundles can pass through the center of the mount and attach to the vehicle under test.

The rotary mount design shall include a mechanical lock manually actuated to lock the mount in a fixed loading position in respect to the chamber door. This loading position will allow loading carts to move to a position in the center of the chamber for lifting a vehicle or module from the cart by means of four fixed hoists located above and available for lifting items inside the chamber.

The controls associated with the turntable shall provide remote and local off-on control with continuous visual indication of position. Provisions shall be made for continuous recording of turntable position at the remote operating position during test so that test results can be coordinated between position of vehicle with respect to solar and albedo simulators. Control shall be provided so that the mount can be stopped within $\pm 5^{o}$ of the selected point.

7.2 Chamber B

7.2.1 Operating Conditions

a. The chamber shall provide a simulated space environment for spacecraft modules up to 13 ft in diameter and 14 ft high. The vehicle mount shall be capable of supporting spacecraft weighing 40,000 pounds.

b. The chamber shall be designed for "man-rated" operations.

c. The chamber shall be designed for a pressure level 10^{-4} torr or better with a specified total gas leak load of 25.6 torr - lit/sec, as specified in Section 8.1.6.

d. The chamber shall be pumped down to stable test conditions in 3 hours or less.

e. The chamber shall be lined with liquid nitrogen cooled heat sink walls to obtain a working temperature of approximately $100^{o}K$.

f. A simulated lunar plane shall be provided. It shall operate at controlled temperatures ranging from $100^{o}K$ up to $400^{o}K$ as specified in Section 7.2.4.

g. A solar radiation flux controllable between 25 and 140 watts per sq ft shall be provided to irradiate an area of 25 sq ft. The simulator shall be located external to the chamber.

h. The chamber and all of the supporting auxiliaries shall be designed to provide an uninterrupted design test environment for a period of 30 days.

i. Provisions for future upgrading shall be as specified elsewhere in the design criteria.

7.2.2 General Arrangement of Chamber B - The space chamber shall be approximately 35 ft in diameter and 43 ft high with two ellipsoidal $^D/3$ heads. The top head shall be removable for installaing test vehicles and equipment. A fixed lunar plane platform shall be provided in the lower portion of the chamber, and the spacecraft module shall be supported on this platform. All of the interior walls above this platform shall be lined with heat sink panels. The lunar plane shall be located at the same level as the Chamber Building ground floor. A solar simulator shall be located on the top of the chamber with the actual simulator module located external to the chamber. A doulbe manlock shall be provided at the lunar plane level for personnel access.

7.2.3 Chamber Vessel - The chamber shall be approximately 35 ft in diameter and 43 ft high with top and bottom ellipsoidal $^D/3$ heads. It shall be fabricated of austenitic stainless stell plate with a clean mill finish. External stiffeners shall be fabricated of carbon steel. The chamber shall be designed for an external pressure of 14.7 psia.

A double manlock shall be provided for personnel access to the chamber during a test period. It shall be composed essentially of two parallel single locks with an interconnecting door. Manlock doors to the chamber and the interconnecting door shall be designed for full atmospheric pressure on either side; while the exterior doors shall be designed for full atmospheric pressure on the outside face. Each lock unit shall have a diffusion pump connection, three umbilical connections, adequate view ports and a nominal floor area 9 ft by 10 ft (capable of handling three men). Except for the chamber side door of stainless steel the lock shall be constructed of carbon steel.

Apertures in the chamber wall proper shall be provided for diffusion pump and mechanical pump intakes, repressurization piping lines, and the solar simulator. Additional smaller penetrations shall be provided as required for cryogenic lines, umbilical connections, and viewing ports. All penetrations and openings in the chamber vessel shall be sealed in accordance with best "state of the art" practice for vessels operating in the range of 10^{-7} torr.

Provisions for upgrading shall include allowance of space around solar simulator and diffusion pumps for future addition of simulators and pumps as well as providing a chamber with leak tightness to allow for a lower pressure level. Ports shall be provided in the vessel for future installation of side solar and albedo simulation units. In addition, clearance over the chamber shall be adequate to allow for a future addition of a 10 ft. high ring extension.

7.2.4 Lunar Plane and Fixed Platform - Chamber B shall be provided with a Lunar Plane which shall be the surface of a fixed mount for support of the test vehicle. The Lunar Plane shall provide varying temperatures in the ranges of 100°K to 130°K and 300°K to 400°K. The low temperature range shall be obtained with a liquid liquid nitrogen cooled heat sink mounted to the solid floor plate, and the high temperature range shall be obtained with electrical strip heaters. During operation the 400°K may be attained and held for a maximum of 48 hours during a two week test time or two hours during a 48 hour test time. The maximum test duration shall be 30 days.

The Lunar Plane shall be solid plate fabricated in sections. The material shall be black anodized aluminum providing an emissivity above 0.9 on the upper side only. The lower side shall be chemically cleaned only. The heating cable and cooling tubes shall be installed on the underside prior to anodizing.

The fixed mount shall be capable of supporting a 40,000 lb vehicle, 13 ft in diameter. The design of the mount shall be compatible with the chamber design and allow sufficient circumferential clearance for emergency repressurization gas flow.

The design of the mount shall be such that it could be converted to a rotary mount at a later date. The prime mover and associated gear drive shall not be included initially, but necessary space shall be provided by means of a spacer to incorporate these items later.

Provisions in the design shall be made to allow a hard line instrumentation bundle to pass through the center of the mount to the vehicle under test.

8.0 Operation Systems

8.1 Vacuum Systems

8.1.1 General - Adequate pumping speed shall be maintained for each chamber throughout the specified operating range to

furnish:

a. Sufficient capacity for progressive volumetric depletion of the gas in the chamber.

b Sufficient capacity to handle the total gas loads during test operations.

c Adequate capacity to pump the chambers down within the specified overall time cycle.

8.1.2 Roughing Pumps - A common installation of vacuum pumps consisting of Roots-type mechanical vacuum booster pumps and oil sealed rotary vacuum pumps shall be provided to serve both chambers. Valves shall be provided to isolate the chamber being pumped down.

The final selection of vacuum pump capacity, motor horsepowers, and physical arrangement in the pumping system shall be governed by the more stringent of the pumpdown cycles specified for the two chambers.

8.1.3 Backing Pumps - Each chamber shall be provided with a separate system of backing pumps for the chamber diffusion pumps and they shall be sized to afford maximum throughput under all conditions of operation.

8.1.4 Diffusion Pump Stations - The diffusion pumps provided for both chambers shall be combinations of the following two sizes:

a. Pump Type A - Nominal capacity equal to 30,000 lit/sec. with maximum stability in the pressure range of 10^{-3} torr. This pump shall have a speed plateau extending over the entire diffusion pumping range specified for Chamber A and Chamber B.

b. Pump Type B - Nominal capacity equal to 50,000 lit/sec. with maximum stability in the range of 6 to 7 x 10^{-4} torr and below. This pump shall have a speed plateau extending over the entire diffusion pump range specified for Chambers A and B.

8.1.5 Chamber A - The chamber vacuum system shall be capable of reducing pressures from sea level to 10^{-5} torr and sustaining this level throughout the entire test duration with a spacecraft in the chamber.

The system shall be designed to obtain this vacuum level with the following gas leakage rates:

a.	Extra vehicular suit (2)	5 torr lit/sec	100% oxygen
b.	Spacecraft	7.8 torr lit/sec	50% oxygen 50% nitrogen
c.	Lunar propulsion allowance	1.0 torr lit/sec	100% nitrogen
	Sub-Total	13.8 torr lit/sec	
d.	Virtual leakage from vehicles Actual leakage of facility Outgassing from vehicle surface		
	Sub-Total	13.8 torr lit/sec	
	TOTAL	27.6 torr lit/sec	

The vacuum pumping system shall be designed to pump this chamber down to stable test conditions with the above gas leakage rates within 24 hours.

This chamber shall be provided with not less than 4 Type A and 10 Type B diffusion pump stations. In addition, Chamber A shall be provided with approximately 1180 sq ft of cryo-condensing pump surface with a total pumping speed of not less than 3,000,000 lit/sec. The cryo-condensers shall be gaseous helium cooled to operate at 20° K and shall be mounted between the upper and lower balcony levels. Each cryo-condenser shall have an independent supply and return line with isolating and control valves.

8.1.6 Chamber B - The chamber vacuum system shall be capable of reducing pressure from sea level to 10^{-4} torr and sustaining this level throughout the entire test duration with a spacecraft in the chamber.

The system shall be designed to obtain this vacuum level with the following gas leakage rates:

a.	Extra vehicular suit (2)	5 torr lit/sec	100% oxygen
b.	Spacecraft	7.8 torr lit/sec	50% oxygen 50% nitrogen
	Sub-Total	12.8 torr lit/sec	
c.	Virtual leakage from vehicle Outgassing from vehicle surface Actual leakage of facility		
	Sub-Total	12.8 torr lit/sec	
	TOTAL	25.6 torr lit/sec	

The vacuum pumping system shall be designed to pump down this chamber to stable test conditions with the above gas leakage rates in 3 hours or less.

This chamber shall be provided with not less than 4 Type A and 8 Type B diffusion pump stations.

8.1.7 Man Locks - Each man lock shall have its own mechanical vacuum pumping system. These systems shall have the following capability:

a Provide lock evacuation from sea level under emergency conditions at rates compatible with man-rating considerations.

b Provide lock evacuation in the presence of a gas load imposed by extra-vehicular suit leakage of 5.0 torr lit/sec.

c Provide lock evacuation under condition (b) above to a pressure level where the resultant pressure surge in the main chamber at its operating level will be relatively small.

8.2 Refrigeration System

8.2.1 Gaseous Helium Refrigeration - A dense gaseous helium refrigeration plant shall be provided to maintain the cryo-condensing panels in Chamber A at a temperature of 20°K. It shall be capable of at least 30 days continuous operation.

8.2.2 Cryogenic Panels - In addition to the cryocondensing panels, previously described for Chamber A, a liquid nitrogen cooled heat sink surface shall be provided on the inside surface of both chambers, all man lock doors, and the vehicle loading door on Chamber A. Surfaces shall be black anodized aluminum with a surface emissivity of 0.9 or better on the side facing the test area. The surface facing the chamber walls shall be chemically cleaned aluminum. The surface shall be optically tight with the exception of penetrations for top and side solar simulators, albedo simulators, and viewing ports. All penetrations shall be provided with a cryogenically cooled collar from the chamber wall to the heat sink array. The panels shall be arranged in appropriate zones for temperature control. The heat sink panels shall be located at sufficient distance inside the chamber wall for access to piping and the rear of panels. Heat sink panels shall also be provided to protect the cryopump surfaces in Chamber A from direct thermal radiation, while maintaining maximum conductance for gas molecules to impinge upon the cryopump surfaces.

8.2.3 Cryogenic Piping - The piping lines and headers for both the liquid nitrogen and the gaseous helium cooling systems shall be designed with due consideration for future coolant requirements of the upgraded chambers.

The nitrogen piping network shall supply liquid nitrogen to the headers of both Chambers A and B. A return system of headers shall collect liquid nitrogen from the cryopanels and shall return this to the nitrogen reliquefaction plant.

A piping network shall be provided for the gaseous helium system to supply helium to the panel headers and return heated gaseous helium to the helium refrigeration plant.

8.2.4 Insulation - Insulation shall be designed to minimize the heat gain to coolant piping systems and to the cryoarrays. Chamber insulation shall be in the form of reflective panels placed between the inner chamber surfaces and the heat sink surfaces.

8.2.5 Nitrogen Reliquefaction - A nitrogen reliquefaction plant shall be provided to condense gaseous nitrogen returned form the heat sink recirculation system and to return liquid nitrogen to the recirculation system. Capacity of the plant shall be adequate to maintain heat sink panels in Chamber A and Chamber B simultaneously at a temperature of $100^{\circ}K$ and to provide refrigeration backup for the helium refrigeration plant Design of the nitrogen refrigeration system shall be based upon various combinations of heat loads occuring with lunar planes at $400^{\circ}K$ and a simulated noon sum, with lunar planes at $330^{\circ}K$ with side radiation simulating a sun at 45°, and with a full

side sun. Consideration shall be given to the relatively short duration of lunar operation, which is 2 hrs during 48 hr test period or 48 hrs during a 14 day test period, and the excess cooling capacity required only for the lunar planes shall be provided by stored liquid nitrogen to assist during that peak load in the test cycle.

8.3 Solar Radiation Systems

8.3.1 General Provisions - Solar flux simulation systems shall be designed with a variable and controllable intensity of 25 to 140 watts/sq ft. to provide for earth orbit test of vehicles with surface material absorptivity characteristics approximating those of aluminum. Furthermore, the maximum deviation from the root mean square intensity for the entire area of illumination shall not exceed ?0 percent of the mean value.

The radiation shall have a maximum half angle collimation not greater than 10 degrees. The spectrum shall be the equivalent of that from a high pressure Xenon gas filled lamp.

The solar simulator shall be composed of an arrangement of modules located external to the space chambers so that excessive heat can be kept out of the chambers with only the radiant flux energy being admitted into the chambers. Each module shall be composed of banks of 5 KW Xenon lamps, reflectors, and lens arrays, and it shall be capable of generating a flux and focusing it for projection into the chambers in a pattern that shall give the prescribed uniformity over the design area.

The modules shall be arranged so that internal parts may be readily serviced and so that the module itself may be removed from its position on the chamber wall. The modules shall be provided with adequate cooling apparatus and ventilation so that the flux generators will operate efficiently and compartments will be safe for servicing.

Albedo flux simulation shall be provided with modules similar to the solar simulator except that the albedo simulators shall provide a variable and controllable flux intensity to 65 watts/sq ft.

The solar and albedo simulators shall be capable of operating over a 30 day test period.

8.3.2 Chamber A Radiation - Chamber A shall be provided with a top and side solar simulator. The top sun shall irradiate an area 13 ft in diameter, and the side sun shall irradiate an area 13 ft by 40 ft high. The modules shall be spaced approximately 5 ft on center.

Albedo flux simulators shall be provided in the chamber wall 180° from the solar side wall simulators.

Additional ports in the chamber wall shall be provided for upgrading the solar and albedo simulation systems. Future solar requirements for Chamber A shall be to provide a top sun irradiated area 25 ft in diameter and a side sun irradiated area 25 ft by 75 ft high. Future albedo requirements shall be to provide two additional simulators each equal in output to the present system.

8.3.3 Chamber B Radiation - Chamber B shall be provided with one top solar simulator. The top sun shall irradiate an area of 25 sq feet. This unit shall be similar to the modules provided for Chamber A.

Additional ports on the top and side shall be provided for upgrading of the solar simulation system. Top sun upgrading shall require irradiation of an area 13 ft in diameter; while side sun upgrading shall require irradiation of an area 13 ft by 14 ft high.

8.4 Repressurization Systems

8.4.1 General - Both Chamber A and Chamber B shall be provided with two completely separate and independent means for repressurization. These two systems shall be the Normal Repressurization System and the Emergency Repressurization System.

Each system shall be provided with local and remote control and indication.

8.4.2 Normal Repressurization System - A Normal Repressurization System shall be provided for each chamber to bring the pressure from operating conditions up to atmospheric pressure after the heat sink and cryopump surfaces have been warmed up to near ambient temperatures.

The system shall be designed to raise the chamber pressure to 5 psia within a 30 minute period. It shall also be capable of repressurization to 14.7 psia within about 3 hours for each chamber.

Prior to introducing air into the chambers the systems shall be arranged so that dry gaseous nitrogen is admitted to raise the pressure to about 5×10^{-4} torr. All of the air admitted to the chamber shall be filtered and dehumidified to insure that the air which enters the chamber will not have a relative humidity greater than 50 percent during repressurization to atmospheric conditions over a 3 hour period.

8.4.3 <u>Emergency Repressurization System</u> - An Emergency Repressurization System shall be provided for each chamber to insure extremely rapid partial repressurization rates and the capability of providing higher oxygen partial pressures than can be obtained with air.

All of the air shall be filtered prior to being admitted into the chambers.

Compressed gaseous oxygen shall be provided for enrichment of the mixture of repressurization gas admitted to the chamber. An amount of oxygen suitable for one repressurization shall be stored separately for each chamber.

The emergency repressurization system shall be designed to satisfy the following requirements of pressure and temperature for each chamber.

a. The chamber pressure shall be raised from operating pressures to 1.0 psia (total) within 10 seconds after valve actuation.

b. Within 30 seconds after valve actuation the chamber shall have an oxygen partial pressure of 1.6 psia.

c. The oxygen partial pressure shall be 2.5 psia within 45 seconds.

d. The total pressure in the chamber shall not exceed 5.0 psia $\pm$0.5 psia as a result of operation of the emergency repressurization system.

e. Total dynamic pressure on objects within the chamber shall not exceed 15 pounds/sq foot.

f. Oxygen gas shall not be admitted to the chamber until 5 seconds after the air admission valves have been actuated, and after diffusion pump valves have been closed.

g. The gas temperature in an area between about 3 ft and 10 ft above the chamber operating floor shall be within the following limits:

1. -30^{o}F to $+200^{o}$F within the first two minutes after valve actuation.

2. -15^{o}F to $+150^{o}$F within the first five minutes.

3. $+35^{o}$F to $+100^{o}$F within the first ten minutes.

Depletion of fluids from the cryopump and heat sink surfaces shall commence when the repressurization valves are actuated in order to achieve these temperature levels.

(h) Accoustic levels within the chambers shall be tolerable and shall not cause injury to personnel inside of the chamber.

The system shall be designed so that it will be operable under all conditions including complete loss of electrical power to the complex.

8.5 Facility Control and Instrumentation

8.5.1 General - The control of the facility shall be predominantly centered in the Facility Control room on the upper level of the Administration Building to permit general supervision by the test conductor. The control board for each chamber shall be located within the control room in close proximity to other equipment related to testing in that chamber, such as the test directors console, biomedical console, vehicle ground control and subsystems checkout. To reduce the length of tubing and wiring, each chamber control board shall be located reasonably close to the chamber served. Local boards providing secondary control and supplementary information shall be located in proximity to the system served.

A complete control and instrumentation system shall be provided for all mechanical and electrical systems supporting the chambers including:

a. Vacuum

   1. Roughing
   2. Backing
   3. Diffusion
   4. Cryopumps

b. Heat sinks

c. Solar and Albedo Simulation

d. Rotary mount

e. Lunar plane

f. Repressurization

g. Refrigeration

h. Facility protection, safety shutdown

Primary Control boards for each of the above systems shall be located in the main control room with local boards located adjacent to the systems as required. Controls for the above systems shall be of the manual-automatic type wherein operations are initiated manually with automatic provisions to continue the system operation at the selected level. Controls shall be provided at the above primary control panels to:

a. Permit tests to be performed with accurate conformance to prescribed limits and sequences.

b. Provide maximum safety to men, chambers, and systems under test.

c. Allow the test director to maintain adequate cognizance of the operation of the facility and systems under test.

d. Provide maximum test flexibility.

e. Provide expansion capability.

8.5.2 Instrumentation and Panels - Adequate instrumentation shall be provided to accomplish the control objectives and provide necessary supervisory information. Whenever possible instruments shall be of an established design with proven reliability. Control instrumentation shall be installed in standard industrial self-supporting panels with free access from the rear to all panel mounted components. All facility instrumentation signals, inputs and outputs, wires and tubing shall be run separately from similar components of the test article and data handling systems.

All facility electrical instrumentation wiring shall be routed through patch panels located in the control room near the Facility Control Board. All spare field element electrical leads shall terminate within these patch panels. All unused board mounted instrument terminals shall be extended and terminated at the patch panels.

Adequate instrumentation patch panels shall be provided adjacent to the control room to enable connections to be made between the Data Handling System and the Facility Control System for transmitting selected data on heat sink temperatures, vacuum levels, solar beam levels, and mount position to the computer.

Instrumentation electrical signals other than wide range millivolt signals (spans greater than 20MV) shall be converted to standard

industrial transmission signals thereby assuring a favorable signal to noise ratio. "Wide Range" millivolt instruments shall be of the null-balance type. If low level electrical signals must be used, the runs shall be as short as possible, and they shall be provided with shielding and suitable grounding. All pneumatic transmission signals shall be 3-15 psig. All pneumatic controller outputs shall be a 3-15 psig signal, and where greater final control element pressures are required booster relays shall be used.

8.5.3 Automatic Control Systems - Automatic Control Systems and final control elements shall be designed to fail safe. Interlocks shall be provided to prevent mis-operation of systems and to insure proper operation sequence of interrelated systems.

8.6 Data Handling System - The data handling system design shall provide a completely integrated test article control and instrumentation system. It shall be capable of collecting data from the test article, ecological factors, and the facility from numbers of points and at the speeds required. It shall provide optimum performance in each of the eight basic design criteria.

a. Test Conformance
b. Safety
c. Central Cognizance
d. Optimum Data Form
e. Data Correlation
f. Flexibility
g. Expansion Capability
h. Compatability with Central Data Facility

The data handling system design shall provide all cabling, racks, consoles, and chamber penetrations necessary to provide a complete, flexible interconnection between R & D test equipment and the test article. It shall provide a monitoring station which will permit the test conductor to monitor and control the progress of the test.

It shall provide a monitoring station which will permit monitoring and evaluation of ecological data and safety controls for the assurance of safety of personnel within the chamber.

The data handling system design shall incorporate a digital process computer for automatic collection, integration, correlation, and evaluation of data, for automatic test sequencing, and for reliable, high speed, automatic reaction to emergency situations. The computer shall be capable of accepting supplementary inputs, which may be required in the future for special facility programming purposes, by adding additional scanner modules.

The computer shall provide immediate type out or display of data required on line, and it shall store all other data on magnetic tape in a format compatible with IBM data handling equipment.

9.0 Supporting Facilities

9.1 Chamber Building

9.1.1 General Provision - A building shall be provided to house Chamber A and Chamber B. It shall have adequate floor space around the chambers to allow for moving test vehicles into the chambers, to allow for servicing the chambers and supporting equipment, and to allow for storage of the Chamber B top vessel head.

9.1.2 Superstructure - The superstructure shall have a structural steel frame designed to resist all expected live and dead loads. Live loads shall include the wind and roof load as specified by ASA for the Houston area, the weight of handling equipment plus a 100,000 lb vehicle, and various other loads as required for proper functioning of the plant. Dead loads shall include weight of structure and major pieces of equipment.

The structural steel frame shall be enclosed with panel type siding based on a 4 ft and 8 in module with exposed aggregate finishes and integral insulation to match panels used elsewhere at the Spacecraft Center.

9.1.3 Foundations - Allowable bearing and shear loads of the soil on the site shall be determined. The foundation shall be designed to transmit the loads of the superstructure and foundation weight to the soil without allowing the structure to undergo any unequal or excessive settlement.

The foundations for Chambers A and B shall be reinforced concrete designed for chamber and test vehicle loads and hydrostatic uplift forces. A means of removing incidental water from these pits shall be provided. Basements which extend below water table shall be water proofed.

9.1.4 Handling Equipment - A 50 ton bridge crane with a 10 ton auxiliary hoist shall be provided for handling the Chamber B head, the placement of test articles in Chamber B and handling of test articles and equipment for both Chambers A and B in the test-set-up area. The crane shall be pendant controlled from the ground floor.

Four 25 ton hoists shall be provided over Chamber A for handling vehicle and equipment inside the chamber during chamber shut-down. Hoists shall be so arranged that two hoists will be able to support a 50 ton test vehicle leaving the remaining two hoists free for other service.

Provisions shall be made so that a separately furnished vehicle handling dollie can move a vehicle from the building main access door into Chamber A.

9.1.5 <u>Access</u> - External access to and from the Chamber Building shall be provided for test vehicles and personnel. A service door approximately 30 ft wide by 35 ft high shall be provided at ground floor level, conveniently located for vehicle entrance from 2nd Street. Personnel doors shall be located where necessary to provide adequate traffic flow.

Internal access shall be provided by means of elevators, platforms, stairways, and walkways around the chambers.

The Chamber A end of the building shall have three platform levels above ground floor for access to diffusion pumps, cryo-piping, control valves, manlocks. Platform levels to the chamber shall coincide with those required inside the chamber. The first level shall be a mezzaine which shall be an extension of the Control Room floor in the Administration Building. It shall provide space for local control boards and motor load center controls, and it shall provide equipment access and support for cable trays. Upper platform levels shall be located primarily for accessibility to the single lock, the diffusion pumps, and the single door to the chamber.

Stairways and a personnel elevator shall be provided between ground floor and platform levels. A hoistway shall be provided for lifting equipment such as solar simulator modules, diffusion pumps, and control boards to the various platform levels.

The solar simulator arrays and each array of the albedo simulators shall be provided with a service lift located directly behind the simulators. The lift and simulators shall be enveloped in a shaft vith the shaft providing protection for the lift and a chamber for forced ventilation of the simulators.

The Chamber B end of the building shall have one platform level above grade which shall be an extension of the Control Room floor in the Administration Building. The mezzaine shall provide space for the same type of equipment as described for the Chamber A end of the building.

Stairways shall be provided from ground floor to the mezzaine level and to the chamber foundation level as required. Walkways shall be provided around Chamber A as necessary for access to diffusion pumps and viewing ports. A stairway and walkway also shall be provided for access to the solar simulator atop Chamber B.

9.1.6 Chamber Building Services

9.1.6.1. Heating, Ventilating and Air Conditioning - The Chamber Building shall be air conditioned in the lower areas, from the floor to approximately 30 ft above the floor. The upper section of the building shall be sufficiently ventilated to prevent the temperatures from rising above the maximum allowable value for the electrical equipment.

Sufficient outside air shall be supplied by the heating, ventilating and air conditioning systems to make up for air being exhausted through the solar simulator elevator shafts and for air leakage through openings.

Design of the air conditioning system shall be based on room temperatures of 75°F D.B. and 50 percent R.H. with an outside temperature of 95°F D.B. and 80°W.B.

The air conditioning systems also shall be designed so that 100 percent outside air can be supplied as makeup to the building in the event of a failure of the chilled water system or cooling coils. Steam and chilled water for operating these systems shall come from existing plant services.

9.1.6.2 Compressed Air Systems - Three compressed air systems shall be provided to serve the complex. These systems are Instrument Air, Service Air, and Solar Simulator Lens Cooling. All of the equipment for these systems except various pressure regulators and small filters shall be located in the pump building.

The Instrument Air System shall be supplied by two motor driven, double acting, single stage, heavy duty, non-lubricated compressors. They shall discharge at 100 psig through aftercoolers to individual receivers. They shall supply oil-free air.

Sufficient instrument air receiver capacity shall be provided to safely shutdown the complex during an emergency without makeup from the compressors being required.

Instrument air shall be dried by means of an automatically reactivated air dryer before being distributed into the plant control air system.

a. Service Air System - Compressed air at 100 psig shall be provided for operating power tools and equipment not requiring oil-free air by means of two 100 SCFM single stage, double acting, lubricated, motor driven air compressors. The machines shall discharge through aftercoolers into individual air receivers of approximately 20 cy ft capacity each.

b. Solar Simulator Lens Cooling System - Each of the solar simulator modules shall be supplied with clean filtered air at 2 psig for cooling of the 5 KW lamps. This air shall be supplied from rotary compressors discharging through filters.

c. Solar Simulator Cooling Air System - Each solar simulator module shall be supplied with clean filtered air at a pressure of 1 inch water gauge for cooling of the reflectors, mirrors and lens assemblies. The blowers shall be located in the Pump Building except that the top simulator in Chamber B shall be supplied with an individual blower located on the chamber.

9.1.6.3 Cooling Water Systems - A separate cooling water tower shall be provided for the chamber service water system.

Individual cooling water circuits shall be provided for each of the following equipment groups.

a. Diffusion Pumps

b. Roughing Pumps

c. Solar Simulator Modules

d. Air compressors and backing pumps

Each circuit shall be provided with a full capacity circulating pump and one full capacity spare.

All of the pumps shall be arranged so that they may take suction from a common supply line from the cooling tower.

Makeup water to the cooling tower shall be taken from the existing water distribution system.

Water treatment equipment shall be provided for the systems.

9.2 Facility Administration Building

9.2.1 General Provisions - A Facility Administration Building shall be provided adjacent to the east side of the Chamber Building and it shall provide space for three areas of specific usage. These shall be a biomedical area, a control room, and an administration office area. Appropriate hallways and stairways shall be provided between the areas for internal access.

9.2.2 Biomedical - The biomedical facilities shall be composed of two main portions; one portion shall be for doctors and the other portion shall be for astronauts, and they shall be located on the ground floor.

There shall be compartments provided for doctors as follow:

a. Biomedical chief office
b. Office for secretaries and records
c. Office for medical personnel
d. Supplementary office
e. Nurse quarters
f. Doctor on duty office
g. Food storage room
h. Emergency room

There shall be compartments provided for astronauts as follow:

a. Suit storage room
b. Ready room
c. Suit dress and taping room
d. Astronaut change room
e. Toilet room
f. Shower room

9.2.2 Control Room - A control room shall be provided on the first level above the ground floor. It shall be on the same level as the mezzanine described previously for the Facility Chamber Building. Space for control and instrumentation panels shall be provided for the facility controls, vehicle controls, test conducters, biomedical monitors, and data handling.

There shall be a serviceway provided under the control room floor for access to cable trays and air conditioning ducts.

9.2.3 Administration Offices - An office area shall be provided on the ground floor level which shall contain the following compartments:

a. Central lobby

b. Facility chief office

c. Secretaries' office

d. Four test conductors offices

e. Eight Engineers Offices

f. Three subcontractor offices

g. Conference room

h. Lecture room

i. Toilet rooms

9.2.4 Superstructure - The superstructure of the building shall be two story with a structural steel frame designed to resist all expected dead and live loads. Allowance in the design shall be given to leteral support by the adjacent Chamber Building. The siding shall be complementary to the facility buildings and shall be based on a 4 ft and 8 in module.

9.2.5 Foundations - Foundations shall be designed so that unequal and excessive settlement shall be avoided.

9.2.6 Services - The entire Administration Building shall be air conditioned for summer and winter conditions. Steam for heating, chilled water for cooling, and electrical power will come from the utility tunnel which serves the Chamber Building. Potable and service water and the sanitary sewer shall be connected with the corresponding systems provided by the Center.

9.3 Pump Building

9.3.1 General Provisions - The Pump Building shall provide space for rough vacuum pumps, for instrument, service and cooling air compressors, and nominal space for future pumping equipment as may be required by chamber upgrading.

The Pump Building shall be adjacent to the Chamber Building and Chamber A. Its west wall shall be setback a distance of 75 ft from the centerline of Second Street; thus, the depth of the Pump Building shall determine the setback distance for the Chamber Building.

9.3.2 Superstructure - The superstructure of the Pump Building shall be one story with structural steel frame. Design considerations for loads and integration with facility buildings shall be the same as for the Facility Administration Building.

9.3.3 Foundation - The building foundation shall be designed to carry the loads of the superstructure without unequal or excessive settlement. Foundations shall be provided for the compressors, blowers, and pumps as required.

9.3.4 Services - The building shall be ventilated through wall intake fans and exhaust louvers. Electrical power shall be supplied through a branch utility tunnel from the main tunnel near the street.

9.4 Refrigeration Building

9.4.1 General Provisions - The Refrigeration Building shall provide space for refrigeration and related equipment. Equipment for nitrogen reliquefaction and gaseous helium refrigeration shall be provided. The Refrigeration Building shall be located approximately 60 ft north of the Chamber Building.

In addition to the refrigeration equipment, space shall be provided for a control room and an office, for maintenance and parts storage, for electrical switchgear. Adjacent to the building a liquid nitrogen storage tank shall be provided for peaking capacity.

9.4.2 Superstructure - The superstructure shall be one story with a structural steel frame, and it shall be consistent with the architectural design of the adjacent facility buildings.

9.4.3 Foundation - The foundation shall be designed to carry the loads of the superstructure without unequal or excessive settlement, or excessive transmission of equipment vibration to the other buildings.

9.5 Gas Storage and Cooling Tower

9.5.1 Gas Storage - Storage tanks for gaseous nitrogen and helium shall be provided within or adjacent to the Refrigeration Building. The tanks shall conform to the established setback from the centerline of roads or to a setback distance based on the minimum requirements to protect surrounding personnel and equipment.

Nitrogen high pressure gas storage shall be designed to provide a 6 hour supply of makeup for the liquid nitrogen system.

Helium high pressure gas storage shall be designed to provide a 2 day supply of makeup helium for the cryopumping refrigeration system.

Additional helium gas storage shall be provided to accommodate the helium that would be removed from the helium refrigeration system during shutdown or defrost. This storage shall be designed for the normal pressure of the helium compressor discharge.

9.5.2 Cooling Tower - A cooling water tower facility shall be provided for the Chamber service water system and the Refrigeration Building requirements. The cooling tower shall be divided with one portion being provided for equipment in each of the two buildings. The towers shall be adjoining and shall be designed on the same module. The towers shall be located north of the Refrigeration Building and they shall be arranged to allow for future modules to be added to the refrigeration gas compressor portion of the tower.

9.6 Site Features

9.6.1 Roads - All roads and drives except for the vehicle entrance shall be a hot plant mix bituminous surface on a compacted base course. The vehicle entrance road shall be reinforced concrete. All roads and drives shall be designed AASHO Standard H-20 truck loading. All roads serving the Space Environment Chamber Facility enter the area from 2nd Street which is on the west side of the Facility.

9.6.2 Walks - All walks in the area shall be asphalt on a suitable granular base. From the perimeter walkway around the Facility Administration Building, a walkway shall run to the Technical Services and Central Data buildings and a walkway shall run to the parking lot.

9.6.3 Parking - No parking areas shall be provided adjacent to the Space Environmental Chamber Facility.

9.6.4 Drainage & Landscaping - The finished grade shall be approximately 1 ft above the natural ground elevation except that the Administration Building shall be surrounded by a terrace approximately 1-1/2 ft higher than the general level of the area. The finish grade shall be sloped away from the building face to provide positive drainage toward catch basins and surface ditches which shall carry storm water to the existing drainage control system. No landscaping except erosion protection shall be provided for adjacent ground areas.

9.7 Electrical Power System - A completely integrated electrical system shall be provided commencing with the incomming 12,470 volt underground feeders from the site electric substation.

The design and equipment specified shall be in accordance with applicable sections of AIEE, ASA, NEMA and NEC codes. In the design of electric equipment and materials to be installed within the chambers, consideration shall be given to the suitability and stability of the insulating materials under the conditions of vacuum to be encountered.

A functional and economic division of loads shall be accomplished through the use of several unit substations located around the building. The lighting levels throughout the facility shall be in accordance with the latest IES standards.

Emergency power equipment as required for personnel safety shall be provided for instrumentation and other essential equipment.

9.8 Underground Utilities

9.8.1 Refrigeration Lines Tunnel - An underground tunnel shall be provided to contain the gaseous helium and the liquid nitrogen refrigeration lines between the Refrigeration Building and the Chamber Building. It shall be integrated with the utilidor tunnel system where feasible..

9.8.2 Utilidor - An underground tunnel from the 5 ft facility boundary line shall be provided for routing utility lines to the Facility Buildings. The lines in the tunnel shall include a chilled water line, 12,470 volt electrical feeder lines, a steam line, and a condensate return line.

9.8.3 Buried Utility Lines - The facility shall be connected to the following buried utility lines adjacent to 2nd Avenue.

a. Fire main
b. Sanitary sewer
c. Storm drain

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DESIGN CRITERIA FOR SYSTEMS TEST
UNDER EXTREME VACUUM - CHAMBER D

1.0 Introduction - The effects of a deep space environment (10^{-10} and lower) on equipment and material are today still a relatively large unknown area, in spite of the many investigations, research and development efforts presently proceeding in both government and industry operated facilities.

From results yielded by experiments carried out under less than near space conditions, (10^{-7} to 10^{-9}) potential problem areas and possible solutions have been indicated. The need for a facility, capable of space simulation corresponding to deep space is clearly indicated, to permit further investigations into the behavior of materials and mechanisms, which will exhibit "abnormal" characteristics under such conditions.

It is the intention to furnish design criteria for a test facility, which will provide a sufficient test volume, and vacuum level to yield meaningful data relating to materials and mechanisms, in support of the design of spacecraft intended to operate in the space environment.

The facility shall provide a means for investigating phenomena in the areas of friction, lubrication, material evaporation rates and suitability (such as sealing compounds, potting resins, paints, cements, insulations) and the behavior of mechanisms and motion devices, as well as for other more conventional studies.

2.0 Location - The test facility shall be located at MSC, Houston, Texas, and accommodated in a suitable building structure in the proximity of Chambers A and B to obtain the maximum utility from all equipment, auxiliary services, systems and buildings provided for the overall complex.

3.0 Scope of Design Criteria - The criteria provides basic information to guide the design of the facility in a manner which will result in the evolution of a facility suitable for the intended purpose and capable of future upgrading as progress is made in Technology and the "state-of art" advances.

Information is provided for:

(a) General Design considerations

(b) Performance requirements

(c) Systems and supporting facilities

4.0 Design Criteria

4.1 Test Volume and Vacuum Chamber - A clear test volume 6 ft diameter x 6 ft long, capable of accommodating spacecraft systems of up to 2000 pounds in weight shall be provided. The chamber orientation shall afford maximum ease of test article loading and pre-test instrumentation and checkout. To satisfy these requirements, the chamber shall:

(a) Take the form of a cylindrical vessel assembly with its longitudinal axis vertical.

(b) Be of double wall design suitable for a guard vacuum of 10^{-6} torr.

(c) Have the inner vessel constructed such that it can be cooled to $100^{o}K$ by liquid nitrogen and be provided with cooled extensions into the pumping ducts of the test volume diffusion pump system.

(d) Have provision made for baking out of the inner chamber, by hot gas circulation through integral passages, to temperatures of the order of $250^{o}C$.

(e) Be provided with a helium cooled cryoabsorbtion pumping surface surrounding the test volume and located within the inner chamber. The temperature of this shroud shall be $5^{o}K$ (approx.). It should be provided with "Chevron" type passages of adequate conductance, communicating with the vacuum space surrounding it to afford ducting through which non-condensable gases can be pumped by the diffusion pumping system. It shall present a surface of high absorptivity to the test article to simulate the thermal environment of near space. It shall be bakeable by hot gas circulation similarly to (d) above.

(f) Be provided with a low thermal loss suspension system for the helium cooled shroud within the liquid nitrogen cooled vessel and between the latter and the outer guard vacuum envelope.

(g) Be provided with suitably designed seals throughout specifically between the body portions and the removable heads of the guard vacuum shell and the liquid nitrogen cooled inner chamber.

Seal design shall take into account the maximum permissible leakages, temperature service and cycling anticipated, thermal stresses and relative movements foreseen and simplicity of installation, maintenance and replacement desired.

(h) Be provided with a suspension system of low loss thermal characteristics between the removable head of the guard vacuum shell, the liquid nitrogen cooled inner chamber and the helium cooled heat-sink. The suspension shall make provision for relative alignment, thermal movement and ease of manipulation.

(i) Be provided with a low thermal loss suspension system for the test article (2000 pound load) from the nitrogen cooled vessel head with suitable penetrations through the thermal sink.

(j) Be provided with penetrations, seals, feedthroughs, solar simulator optical elements and necessary other devices, described elsewhere, exhibiting the necessary characteristics for operation in the UHV and XHV environments, from the outside of the guard vacuum shell, through the inner chamber and heat sink into the test space.

(k) Be constructed of materials suitable for the service intended and provided with suitable surface finishes to conform with previous requirements. The material selection shall be governed by temperature considerations, outgassing and diffusion characteristics as well as structural requirements.

(l) Conform to the general dimensions outlined below:

(1) Helium cooled heat sink:

7'-0" diameter x 8'-0" high

(2) Liquid nitrogen cooled inner guard vacuum barrier:

9'-0" diameter x 10'-0" high

(3) Main Chamber (outer guard vacuum barrier):

11'-0" diameter x 14'-0" high

4.2 <u>Vacuum Performance and Pumping Equipment</u> - The chamber and pumping systems shall be capable of providing for operation at the following pressures, under the conditions specified below:

(a) 1×10^{-10} torr, or better without a test specimen in the chamber.

(b) 1×10^{-8} torr, with a specimen imposing a gas load of 6×10^{-5} torr lit/sec.

(c) 1×10^{-6} torr, with a specimen imposing a gas load of 8×10^{-3} torr lit/sec.

Additionally the unit shall provide:

(a) A pumpdown time from 760 torr to a pressure of 1×10^{-10} torr of 24 hours or less.

(b) The ability to maintain uninterrupted stable test conditions at the specified pressure levels for a period of 30 days.

To satisfy these requirements, the pumping equipments shall include:

4.2.1 Test Volume Evacuation

(a) The system shall be of "valve less" design and include:

(1) Primary and Secondary diffusion pumps.

(2) An oil sealed rotary mechanical pump for roughing and backing.

(3) Oil sealed rotary mechanical vacuum pumps for "holding" the diffusion pumps.

(b) Each primary diffusion pump shall be furnished with a damper type water cooled baffle for backstreaming elimination during the period of jet vapor stream formation on heat-up and cool-down. The baffle shall be connected directly to the inlet of the diffusion pump.

The baffle shall be constructed of series 300 stainless steel and the damper actuated magnetically or otherwise, so that the mechanism does not require a penetration or shaft seal.

(c) Above each damper baffle shall be provided an optically dense chevron type, liquid nitrogen cooled baffle trap.

The trap shall be designed for optimum conductance and be bakable at temperatures of 250°C. It shall have a low nitrogen consumption and be fitted with an automatic level control or fueling device.

The baffle shall be welded directly to the 48 in diameter liquid nitrogen cooled, right angle elbow duct of the inner guard vacuum chamber. This duct faces the "chevron" section of the heat sink.

(d) Metallic gaskets or refrigerated elastomer seals shall be used at the flanged joints between the baffle (c) and the damper type device (b) as well as the latter and the inlet to the primary diffusion pump.

(e) Two primary diffusion pumps shall be provided. Each pump shall be connected to the test volume as previously described. The pumping inlets to the test volume shall be located diametrically opposite each other. The primary diffusion pumps shall exhibit the following characteristics:

(1) Nominal speed for air - 50,000 lit/sec.

(2) Operate with a low vapor pressure, high performance fluid such as Dow Corning XF-4660.

(3) Have inherently low back streaming characteristics.

(4) Produce a minimum of thermal decomposition products of the working fluid.

(5) Be filled with an integral anti-back streaming device, such as a "cold-cap".

(f) Two secondary diffusion pumps shall be provided for backing of the primary pumps ((e) above). The pumps shall exhibit the following characteristics:

(1) Nominal speed for air 4100 lit/sec.

(2) Operate with a low vapor pressure, high performance fluid.

(3) Have inherently low backstreaming characteristics.

(4) Produce a minimum of thermal decomposition products of the working fluid.

(5) Be fitted with an integral anti-back streaming device, such as a cold-cap.

(g) Each secondary diffusion pump shall be fitted at inlet with a liquid nitrogen cooled, optically dense chevron type baffle trap. The trap shall be designed for optimum conductance and minimum nitrogen consumption. A liquid level controller shall be provided.

(h) A 400 CFM (nominal) oil sealed, rotary, gas ballasted, mechanical vacuum pump shall be provided for "roughing" the chamber test volume and "backing" of the diffusion pumps for their maximum throughput at chamber pressure levels above the 10^{-5} torr range, during pumpdown cycles.

(i) Two 30 CFM (nominal) oil sealed, rotary, gas ballasted, mechanical vacuum pumps shall be provided. The pumps shall be connected to the forelines of the secondary diffusion pumps, for backing them at chamber pressures less than 10^{-5} torr.

(j) Air operated failsafe valves shall be provided in forelines and provision made for valved leak detector connections.

4.2.2 Guard Vacuum Evacuation

(a) The system shall be of "valve less" design and include:

(1) A primary diffusion pump

(2) An oil sealed rotary mechanical pump for roughing and backing.

(b) The diffusion pump shall be furnished with an optically dense liquid nitrogen cooled baffle trap, positioned directly above it and connected to the main chamber pumping port.

(c) The main chamber pumping port shall be located centrally on the lower dished head of the outer guard vacuum envelope.

(d) The diffusion pump shall exhibit the following characteristics:

(1) Nominal pumping speed for air-32,000 lit/sec.

(2) Operate with a low vapor pressure fluid such as Dow Corning DC 704.

(3) Have inherently low backstreaming characteristics.

(4) Be fitted with an integral anti-backstreaming device, such as a cold-cap.

(e) One 400 CFM (nominal) oil sealed, rotary, gas ballasted, mechanical vacuum pump shall be provided for "roughing"

of the guard vacuum volume and backing the diffusion pump (item (d) above) throughout its operating range at maximum throughout.

4.3 Thermal Environment - A heat sink shall be provided at a temperature which affords the best simulation of deep space from both thermal and pressure aspects.

4.3.1 Heat Sink - The heat sink shall take the form of a liquid helium cooled shroud approximately 7 ft diameter x 8 ft high, surrounding the test space. It shall consist of a fixed bottom cylindrical section, and a removable top cover. The shroud shall incorporate "chevron" type sections, facing the areas of the diffusion pump ducts, to afford optically dense paths of adequate conductance for the removal of non-condensable gasses, while at the same time preserving the integrity of the thermal environment.

The shroud shall carry a high absorptivity surface finish internally to simulate the characteristics of heat space. The top cover shall accommodate centrally the necessary cooled "window" of the solar simulator optical system.

4.3.2 Thermal Shield - The shroud shall be surrounded by a heat shield. This shall be in the form of a liquid nitrogen cooled envelope approximately 9 ft diameter and 10 ft high. This envelope shall consist of a fixed portion and a removable head with a suitable vacuum tight seal between them. The head shall carry the vacuum tight "window lens" associated with the solar simulator optics. The lens shall be centrally and suitably aligned in the head.

The heat shield shall have extensions into the diffusion pump ducts, extending to the entry of the liquid nitrogen cooled baffles.

4.3.3 Miscellaneous

(a) A suspension system of low heat leak characteristics for the concentric heat sink, thermal shield (inner guard vacuum barrier) and main chamber (outer guard vacuum barrier) as outlined elsewhere, shall be furnished.

(b) System for hot gas circulation shall be provided which will afford a means of baking out the heat sink and thermal shield at temperatures of the order of 250°C. The systems shall be such that this bake out temperature can be reached in a relatively short time, of the order of one hour.

4.4 Solar Thermal Radiation - Provision shall be made to afford a means of simulating the solar thermal flux with intensities of 25 watt to 140 watts per square foot and with good spectral distribution.

The illuminated area shall be circular and shall be 3'-6" diameter.

Solar radiation shall be provided by an external module located on the main chamber cover and arranged to project a beam downwards through a centrally located window lens assembly.

A series of internal optical elements shall be furnished which not only provide collimation of this beam but also act as "windows" into the inner vacuum chambers.

These windows and window lens elements shall be progressively cooled from room temperature at the window lens assembly to liquid nitrogen temperature at the intermediate lens and finally to helium temperature at the pseudo Fresnel lens located on the heat sink. The intermediate lens shall furnish a vacuum tight seal between the XHV region within the work space and the guard vacuum.

The overall efficiency of the system from electrical imput to luminous power within the test area shall be of the order of 8 percent, or more.

The illumination at an intensity of 140 watts per sq ft shall be effected by means of 3 or 4 lamps of a total array of seven 5 KW high pressure Xenon arc lamps.

The uniformity over the illuminated area of 3.5 ft diameter shall be 10% of the RMS when measured with a detector of 4 x 4 inch sensitive area. The collimation of the solar beam shall be less than 5° half cone angle. The spectral distribution shall essentially be that of a high pressure Xenon arc lamp.

4.5 Miscellaneous

(a) The chamber shall not be designed as "man-rated".

(b) Penetrations for the following shall be furnished for test article services:

(1) 200 - Thermo couple leads.

(2) Two - 8-inch diameter blanked ports for future additions.

(3) **Port for future addition of motion devices.**

(c) Basic instrumentation shall include:

(1) A helium sensitive mass spectrometer leak detector.

(2) A mass spectrometer capable of residual gas analysis at lowest pressure levels.

(3) Suitable vacuum measuring devices.

(d) One suitable view port shall be provided to permit observation of the central test area.

4.6 Growth - Provision shall be made in the design of the chamber and support facilities for economical future growth in performance capability as technology and state-of-art advances are made.

Such provisions shall include:

(a) Addition of internal motion devices, externally actuated, to operate parts of spacecraft systems under test.

(b) Lower ultimate pressure capability and increased gas load handling ability in the 10^{-10} torr range.

4.7 Support Facilities - The chamber shall be housed in a suitable structural providing the following services:

(a) An overhead crane.

(b) A clean room over which the head of Chamber D can be placed for installation of test articles.

(c) Space for delivery of articles served by the overhead crane.

(d) A facility control room.

(e) Mechanical and electrical systems necessary to support the chamber.

(f) Access and service platforms as required.

A refrigeration plant shall be provided to supply all necessary liquid nitrogen and helium. This pl ant shall be located in close proximity to the chamber building.

Joint use of services, utilities and systems provided for the Chambers A and B facility shall be made where practicable.

INTRODUCTION

The conceptual design of the Chamber A and Chamber B complex which is presented in this section of the report was prepared in order to investigate to the greatest practicable depth the design characteristics of the complex which would lead to pertinent Design Criteria, cost estimate and project construction schedule. The conceptual design may not in all respects be consistent with the Design Criteria due to late developments in requirements and guidance. Where they may differ the Design Criteria are to be considered ruling in future design. The conceptual design offers a basis for pursuing detail design of the facility without further conceptual study, but upon further consideration alternate engineering details may be preferred without conflicting with the Design Criteria.

The Chamber D facility presented is not an integral part of the selected Chamber A and B complex. As a potential facility, Chamber D was of sufficient interest to warrant carrying out its study to serve as the basis of a future project as circumstances permit.

SECTION I
GENERAL FACILITY ARRANGEMENT

1.0 Site and Integration with the Master Plan - The Space Environment Chamber Facility is located at the site of the Manned Spacecraft Center about 20 miles SE of Houston, Texas. This site is essentially level and at about elevation +20 ft above tidal datum. Clear Lake, an arm of Galveston Bay, adjoins the MSC area on the east.

Master planning for location of all center facilities on the site has been accomplished by others. Main roads and underground services for the Center have been laid out and partial construction has been started. All Center services are located underground either directly buried or in concrete tunnels below ground.

The master planning has determined the philosophy of arrangement of facilities about the site. A campus-like atmosphere with attractive structures is desired. To this end, large open areas are provided. Traffic between buildings is by foot. Structures are set well back from streets and parking has been limited to off-campus areas.

The Space Environment Chamber Facility has been planned and located to fit into the master plan. The architectural appearance has been derived from available drawings of Center facilities. The area designated on the master plan for the chamber facility is directly east of Second Street and south of Avenue C. In early discussions with the master planners, it was requested that administrative portions of the Facility be arranged to adjoin the central campus about which are grouped other structures housing similar functions. Likewise the mechanical or shop functions were to be concentrated on the side opposite the campus, hence adjoining Second Street.

Thus, the Space Environment Chamber Facility is located 75 ft east of the center of Second Street to have a set back consistent with other structures along this street. In the north-south direction, the Facility is located as near Avenue C as is feasible with due allowance for expansion in that direction. The site arrangement is illustrated on Fig. I-1. The administration component, housing offices and biomedical facilities, is located on the east side of the Facility facing the campus with foot paths leading to other buildings. Test articles and truck traffic to the Facility enter from Second Street via driveways for this purpose. Tanks and other units requiring truck servicing are located on the Second Street side as are substations and other utilities.

The Refrigeration Building is located to the north of the Chamber Building as near as feasible to Chamber A, the source of greatest heat load. Driveways connect the Refrigeration Building with Second Street to permit truck service from this direction.

The Facility is located so that expansion of the high bay Chamber Building can be accomplished to the southward for a considerable distance if required to house future chambers.

A utilidor is provided from the Facility along Second Street to the presently planned Center utilidor system with a connection at Second Street and Avenue C. Steam lines, chilled water lines and communications are provided in the utilidor to this point. Power feeders, while in the utilidor, are extended to the Center Substation. The Facility is connected to the fire main along Second Street for fire water, potable water and makeup water. Sewer and surface drainage connections to the buried lines along Second Street are also provided.

The ground floor level of the Facility is at elevation 23, thus placing it about 4 ft above the grade of the adjacent avenue. This permits surface drainage in general towards the street.

This ground floor elevation also provides for the approach used elsewhere on the site which places administrative units on a local raised terrace. Since the natural grade is about elevation 20, a 3 ft high terrace is provided on the east side of the Facility adjoining the Administration Building while driveways entering the Facility from Second Street slope upward to accommodate the 4 ft difference in elevation.

The subsoil is generally firm to very stiff clay to considerable depth. Occasional water bearing sand strata occur with ground water near the ground surface depending on the seasonal conditions. Subsoil characteristics and foundations are described in Section VI.

2.0 General Arrangement - The Space Environment Chamber Facility has three major components:

a. Chamber Building
b. Facility Administration Building
c. Refrigeration Building

2.1 Chamber Building - The Chamber Building is a high bay structure enclosing the two environmental space chambers and their related services. The general arrangement of this component is shown on Figs. I-2, I-3, I-4, I-5 and I-6. Chamber A, the man-rated Space and Lunar Surface Environment Simulator, is located at the north end of the Chamber Building and is surrounded by service platforms enclosed within the structure. These service platforms provide access to equipment on the chamber at various levels and also serve to support auxiliary equipment. An elevator is provided at this end of the Chamber Building to facilitate access to the upper platforms, particularly those serving the top of the chamber.

Chamber B, the man-rated chamber for Life Sciences and Astronaut Training, is located towards the south end of the Chamber Building.

A bridge crane in the upper portion of the Chamber Building provides load handling service from the face of Chamber A over Chamber B and beyond, as illustrated in the Building Section, Fig. I-3. This crane also provides a means for unloading test articles delivered to the Chamber Building by truck, removes and replaces the access head of Chamber B and assists in the loading and unloading of test articles in each chamber.

A vertical lift door is provided in the west wall of the Chamber Building for delivery of test articles.

Between the two chambers is a "laydown" area for setup of test articles being prepared for test as well as storage and eventual dis-assembly.

Provision is made for the future addition of a "clean room" for test article preparation adjacent to the "laydown" area and extending towards Second Avenue. A service area is located at the ground floor level to provide a central location for tool checkout, small tool shop, and a wash and locker area for mechanics.

Adjoining the Chamber Building to the west and in close proximity to Chamber A is the Pump Building housing the rough pumping system as well as service water pumps and air compressors.

In addition to traffic circulation at the ground floor level, a means is provided for access between chambers at the mezzanine or + 16.5 ft level. This platform permits maintenance personnel, operators and observers to traverse between chambers and to the control room without descending to the working level at the ground floor. The

platform also serves as a support for wiring trays and piping running between chambers and to the control room.

Around the periphery of the Chamber Building are located outdoor electrical equipment, emergency repressurization inlet filters, and oxygen bottle racks.

2.2 Facility Administration Building - This building adjoins the Chamber Building on the east. It contains the offices and biomedical area on the ground floor and the control room and test conducting room on the upper floor. The arrangement together with an architectural elevation of the facility is shown on Figs. I-7 and I-8.

An entrance lobby, located at the front of the building on the ground floor, controls traffic which can move via hallways directly to the Chamber Building or to the office area and biomed area on either side.

The office space provides a gross area of 7500 sq ft for NASA administrative and technical personnel assigned to the facility. A conference and lecture room for training is included in this area as is space for subcontractors engaged in test vehicle subsystem checkout.

The biomed area provides a gross area of 7500 sq ft for administrative and medical personnel attached to and serving the Facility and for astronaut preparation.

The control room is located on the second floor above the office and biomed area. Facility control boards are located here as well as equipment to check out vehicles under test in the environmental chambers. The common data handling system is located in the center of the room. The northern half of the room is then allocated to control and test equipment for Chamber A while the south half is allocated to Chamber B. The west wall of the control room adjoins the Chamber Building affording a view of the operations in the central area of the floor below.

2.3 Refrigeration Building - Directly to the north of the Chamber Building is located the Refrigeration Building. Sufficient space between the buildings is allowed for truck access and erection clearance. The gaseous helium refrigeration system is located in the section of the building nearest the chambers. The liquid nitrogen refrigeration equipment is located beyond since the operating temperatures are somewhat higher. Located between the building and Second Avenue is the liquid nitrogen peaking tank requiring truck deliveries.

SECTION II - A
VESSEL

1.0 Size, Shape and Orientation - The vessel is shown on Fig. II-3. It consists of a 65 ft diamter vertical cylinder with a hemispherical top head and a D/3 ellipsoidal bottom head. The total over-all height is 120 ft-2 inches. The bottom of the vessel is 26 ft below the main floor of the building.

The invert of the 40 ft diameter circular opening is located approximately 5 ft above the lower tangent line and about 1 ft above the Chamber Building ground floor. The opening is oriented in the vessel to face along the length of the building towards the unloading area and crane bay.

2.0 General Structural Details

2.1 Plate and Stiffeners - The shell and heads for the vessel are calculated to have the same factor of safety in the plate (approx. 2.5) as an unstiffened sphere designed by ASME code procedures. The factor of safety for the stiffeners is approximately 3 against ring instability. Designing to these criteria, the plate thicknesses, stiffener sections, and maximum stiffener spacing is approximately as follows:

	Plate "t"	Stiffeners	Max. Spacing
Top Head	.59"	6 x 4 x 3/4" angle	51"
Cylindrical Shell	.87"	ST 12 WF 50	60"
Bottom Head	.82"	ST 10 WF 41	68"

2.2 Large Opening Reinforcement - The proposed method of reinforcing the opening for test vehicle passage is shown on Fig. II-3. The design of this section considers the bending and thrust stresses caused by the unequal biaxial loading imposed by the cylindrical shell as well as the shear and torsion resulting from the pressure force on the door acting radially to the cylindrical shell.

Consideration was given, in determining the allowable stresses, to the resulting deflections of the door flange. It is important that these deflections be limited to insure an adequate seal at this critical location.

2.3 Penetrations - Welding details incorporated in penetration design are in accordance with high vacuum practice. That is, welds attaching the nozzles or pipe to the vacuum chamber shell either provide

100% penetration or a means for entrapped gas to escape to the atmosphere. A method for doing the latter is to weld continuously the inner surface of the joint and weld the outer surface (the atmospheric side) intermittently.

2.4 Supports - The supports for the chamber are of conventional design since no unusual thermal or dynamic movements are expected. The column layout on Fig. II-3 shows 10 - 12 inch wide flange structural columns uniformly spaced around the chamber and attached approximately at the lower tangent line.

2.5 Main Door - The main door consists of a spherical plate cap dished to carry pressure on the concave surface. This cap is welded to a built-up compression ring and flange. Structural stiffeners are placed around the periphery to provide stability and to limit deflection.

Rotation of the door during opening and closing is guided by side hinges attached to the chamber wall. The weight of this door is carried during movement by a rolling bottom support.

Only a minimum number of bolts or clamping devices are provided since the atmospheric pressure will provide the necessary sealing force during operation.

3.0 Material and Finish - The shell plate material is AISI Type 304 stainless steel with a normal mill finish. The various nozzles and flanges and internal structural elements are constructed from the same plate material as the shell.

External structural elements such as shell stiffeners, penetration reinforcement (where required) and vessel supports are structural quality carbon steel.

The internal balconies are aluminum and are bolted to stainless steel brackets welded to the chamber wall.

4.0 Personnel Locks - One double manlock and one single manlock are provided in the chamber. The double manlock provides personnel entry from the main Chamber Building floor; the single manlock, from the platform at elevation + 56. An additional door, which may be used with a future lock, is installed to provide access from the floor at elevation + 86.

The arrangement and preliminary details of the lock are shown on Figs. II-4 and II-5.

The lock shells and doors, excepting the doors through the chamber wall, are constructed of carbon steel.

The doors through the chamber wall are stainless steel. Each door is provided with O-ring type seals.

The inner and outer doors will hold against pressure acting toward the chamber only. A simple manually operated latch is provided to hold the doors closed until the evacuation of the chamber is started. After this time the pressure differential across the door completes the seal and prevents accidental opening.

The door between the two chambers of the double manlock will hold against pressure acting from either side.

All doors are manually operated and no provision is made for powered or remote operation. No door interlocks are included.

5.0 Hoists - Four 25 ton capacity, electrically operated, conventional cable and drum hoists are located above the top head of the vessel and are supported by the vessel. The lifting hooks are lowered into the chamber through four 3 ft diameter penetrations in the vessel head. The hoists are located on a circle of 18 ft radius as shown on Figs. II-1 and II-2. Two of the hoists are placed on the centerline of the main 40 ft diameter door. The other two hoists are on the chamber centerline 90° thereto.

It is contemplated that two diametrically opposite hoists can lift the heaviest vehicle while the other two are available for related test setup operation.

6.0 Personnel Access (Internal) - Personnel can enter the vessel at the double lock at elevation +27, the single lock at elevation +56 or the door at elevation +86. The double lock is at the level of the vehicle support turntable which, with an annular ring of grating platform, provides personnel access over the entire chamber within the heat sink walls at that level.

The single lock at elevation /56 leads to an internal 5 ft wide perimeter walkway which extends approximately 90° around the chamber in each direction from the door as shown on Fig. II-1. This walkway provides a means for astronaut access at this level to test vehicles. For maintenance purposes, the walkway may be temporarily extended around the remainder of the chamber perimeter permitting access to the front of the solar simulator and vehicle entry door.

The single door at elevation /86 provides access to a perimeter platform (similar to that at elevation /56) extending around the full circumference, interrupted only by the side solar simulator and the albedo radiation paths. At present this platform is used primarily for maintenance and test setup operations. When the personnel lock is added at this level, this platform will also provide means for astronaut access to the top of the tallest vehicles contemplated for the chamber. From these three access levels it is contemplated that individual catwalks or ladders will be provided to bridge between the permanent platforms and the test articles.

7.0 Penetrations - Vessel penetrations are required for vacuum pumps, cryogenic piping, solar simulator ports, electrical and instrumentation lines, viewing ports, umbilical connections to space suits, and repressurization inlets.

7.1 Vacuum Pump Penetrations- Fourteen 48 inch diameter nozzles are provided in the cylindrical portion of the chamber for connection to diffusion pumps. One 36 inch diameter nozzle is provided for the roughing pump connection.

7.2 Cryogenic Penetrations - For liquid nitrogen supply and return, sixty-four 6 inch diameter penetrations are provided. (See Fig. II-6) For vacuum jacketed helium supply and return, sixteen 4 inch diameter penetrations are provided. (See Fig. II-7)

7.3 Solar Simulator Ports - For the side solar simulator ports both present and future, sixty-four 18 inch diamter flanged nozzle penetrations are provided. For the top solar simulator 21 similar penetrations are provided.

For the three albedo simulators on the side walls, a total of 48 similar penetrations are provided. The penetrations which are used for the initially installed solar and albedo simulators are made vacuum tight by the quartz lens and vacuum seal as described in Section II-D-2. Those penetrations which are provided for installation of future solar and albedo simulators are blanked off with a stainless steel vacuum tight cap or 10 inch view port assembly.

7.4 Electrical and Instrumentation Penetrations - Multiple electrical instrumentation penetrations are sealed in sleeves which are mounted in a flange plate. This assembly can be shop tested for vacuum tightness before installation and welded or bolted into a shell penetration without damage to the vacuum seal.

Electrical power penetrations are accomplished by means of hermetically sealed bulkhead fittings on shop-assembled and shop-tested panels which are welded to the vessel wall.

Multiple penetrations for instrumentation are located in the base and on the side of the chamber. Those in the base are for connections to the vehicle through the turntable, and those on the side are for umbilical connections to the vehicle. The latter are at the intermediate platform level.

Electrical power penetrations for the lunar plane heaters and for the turntable drive motor are located at the base of the chamber. Light duty power penetrations for general use and internal illumination of the chamber are located on the top head and at the access levels.

7.5 Viewing Port Penetrations - Penetrations are provided in the chamber and manlock walls for 10-inch diameter viewing ports required for visual surveillance of the locks and the chamber during vacuum operation. At the single lock two interior and two exterior viewing ports are provided as shown on Fig. II-4. At the double lock nine viewing ports are provided; four into the chamber, four to the exterior and one between the locks as shown on Fig. II-5. At the single door at elevation +86, two are provided.

In addition to the viewing ports associated with the lock and door entrances, four are provided at the ground floor level, four at the elevation +56 platform, four in the future solar simulator ports on the head of the vessel, and four in the future albedo ports on the side of the vessel.

7.6 Umbilical Penetrations - For umbilical connections to space suits within the locks or chamber, 10-inch diameter penetrations are provided. There are three penetrations in each lock and 10 penetrations in the chamber wall, five of which are located at the lunar plane level and five at the elevation +56 ft platform level. The services which feed through the umbilical connections are described in Section IX.

7.7 Repressurization Penetrations - Five 36 inch diameter penetrations are provided in the bottom head for the repressurization system, one for the normal repressurization system and four for the emergency system.

8.0 Ventilation

8.1 Chamber Ventilation and Cooling - Chamber A is ventilated for normal occupancy during maintenance periods by chilled or warmed air supplied by air handling units complete with fans followed by heating and cooling coils connected into the normal repressurization system piping. Air is exhausted from the top of the chamber by an exhaust fan mounted on the roof of the building. The fan is connected to openings in the chamber top having a normally closed vacuum valve.

This system takes its air from the outside through automatic roll type air filters. The air quantity will be 22,500 CFM which is equivalent to 3 air changes per hour.

Face and bypass dampers over the coils will be operated by a thermostat, with bulb located in the exhaust air duct at the top of the chamber to control the temperature within the chamber.

Ventilation of the chamber is based upon diluting trichloroethylene cleaning solvent fumes in the chamber to the maximum allowable concentration, as recommended by the American Conference of Governmental Industrial Hygienists.

8.2 Side Sun Lamp Module Elevator Shaft - The elevator shaft is cooled to approximately 85°F by 75°F air from the main building. The air is drawn through openings in the elevator shaft by an exhaust fan mounted on the roof of the building directly over the elevator shaft. The air is exhausted directly outside.

The air required when 18 modules with seven lamps each are operating at full output is 4500 CFM.

8.3 Top Sun and Albedo Lamp Modules - The heat released from the surfaces of these modules will be dissipated in the Chamber Building, from whence it will be removed by the Chamber Building ventilating system.

SECTION II - B

CRYOARRAYS

1.0 Heat Sink and Thermal Shields

1.1 Thermal Loads - Calculated thermal loads for the heat sink and thermal shields are indicated in the following table:

HEAT SINK AND THERMAL SHIELDS
THERMAL LOADS *

LUNAR LANDING

Operating Temperature	400°K		330°K	
Target	13' x 40'	25' x 75'	13' x 40'	25' x 75'
Heat Leak	27	27	27	27
Vehicle	4	4	4	4
Solar Simulator	21	95	68	225
Albedo	-	-	-	-
Lunar Plane	240	240	110	110
Motor	-	-	-	-
Sub-total	292	366	209	366
Pumpwork	18	23	13	23
Total	310	389	222	389

EARTH ORBIT

Orientation	Side Sun		Top Sun	
Target	13' x 40'	25' x 75'	13' x 40'	25' x 75'
Heat Leak	35	35	35	35
Vehicle	4	4	4	4
Solar Simulator	95	315	21	95
Albedo	48	157	48	157
Lunar Plane	-	-	-	-
Motor	30	30	30	30
Sub-total	212	541	138	321
Pumpwork	13	34	9	20
Total	225	575	147	341

* Loads are in kilowatts

1.2 Nitrogen Requirements - A 280 KW liquid nitrogen reliquefaction plant is furnished. As shown on Fig. V-1, an additional peak load exists for a 2-day test period. The additional capacity is supplied by liquid nitrogen from storage.

1.3 Panel Design and Arrangement - Heat sink cryopanels consist of 1 3/8 inch OD tubing on 6 inch centers, brazed or welded in a serpentine pattern to the backs of 1/8 inch thick aluminum. The sides of the heat sink cryopanels which face the chamber wall are chemically cleaned to provide an emissivity of less than .1. The sides of the cryopanels which face the vehicle are anodized with a black dye to approach a black body emissivity of above .9. Panels are flat with 2 inch breaks on each side for structural rigidity as shown on Fig. II-8. Five rows of rectangular vertical panels are arranged about the perimeter of the vessel. Three horizontal rows of panels of equal length (approximately 10 ft) cover the area between the lower catwalk and the lunar plane. The fourth row of 29 ft long panels cover the area between the two catwalks. The fifth row of panels covers the remaining area along the straight sides of the chamber, between the upper catwalk and the point where the dished head begins. The rectangular vertical panels present a heat sink surface of approximately 8,340 sq ft.

Heat sink panels for the dished head of the chamber are trapezoidal in shape, arranged in two rings between the vertical panels and the solar top plate. These panels present a heat sink surface of approximately 5,000 sq ft.

Heat sink panels for the flat solar top plate and the solar side plate are identical in configuration with the vertical side panels. These panels present a combined heat sink surface of approximately 1,930 sq ft. Tubing for future solar simulation heat sink panels is designed so that additional solar simulation can be added by simply cutting out the required penetrations.

Square pyramidal heat sink sections constitute the configuration of the collars extending from any penetration of the heat sink to within a 2 inch clearance of the outer wall or solar ports. These penetrations include the top and side solar simulators, the albedo simulators, and the four top access openings. Total heat sink surface of the collars is approximately 400 sq ft.

Configuration of the heat sink panels for the lock doors and the vehicle loading door is similar to that for the vertical side panels, except that adequate means of protecting persons from sharp corners is incorporated into the design of the lock door panels. Flexible hose is provided in the lock door panel design to allow the panel to operate when the door is opened. Piping in the vehicle loading door panels will have to be disconnected whenever the door is opened. Total door heat sink area (vehicle loading and lock doors) is approximately 1,860 sq ft.

Chevron type heat sink panels are supplied for the repressurization louvers which extend from the vertical side panels to the lunar plane. Total heat sink surface for the louvers is approximately 2,000 sq ft.

Lunar plane heat sink panel configuration is similar to that for the vertical side panels except that the tubing is applied to the underside of the 1/2 inch floor plate. Total lunar plane heat sink surface is approximately 1,600 sq ft.

In addition to the above mentioned panels, certain panels are required for shielding the catwalks. The configuration of these panels is dictated by the need for presenting an optically tight heat sink surface to the test vehicle.

With the exception of the door panels, which are attached to the doors, all heat sink panels are attached to the chamber wall or catwalks with sufficient strength to support the weight of the panel, accumulated frost, and refrigerant. Sufficient freedom of movement is provided to allow for thermal contraction and sufficient support is provided to prevent undue panel flexing on rapid repressurization.

Thermal radiation shields, identical in configuration and panel finish with the vertical side heat sink panels, are mounted on the vehicle side of the heat sink to screen the cryopump panels from the vehicle's view. Radiation shield surface is approximately 1,770 sq ft.

See Fig. II-9 for isometric layout of heat sink array.

1.4 Pressure and Operating Temperature - The liquid nitrogen heat sink operates at a pressure of approximately 65 psig with an inlet temperature of 81°K and a maximum outlet temperature of 95°K.

1.5 Control Zones - Each control zone is composed of approximately 600 sq ft of panel surface to accommodate a flow of approximately 126 gallons per minute of liquid nitrogen. Approximately 32 zones are required. This guarantees a heat pickup of 84 KW per zone, which corresponds to 140 watts per sq ft and is sufficient for future testing. See Fig. II-10 for typical zone schematic.

1.6 Manifolding and Valves - Each zone is supplied from a 2-1/2 inch aluminum pipe header and is discharged through 2-1/2 inch aluminum pipe to a 4-inch stainless steel collection header. Zone headers are located in the chamber with supply and discharge piping to each zone penetrating the chamber wall. A temperature control valve is installed in the outlet piping from each zone to control the flow of liquid nitrogen through each zone.

1.7 Supply Piping - Supply piping from the reliquefaction system to the zone headers is 4 inch stainless steel. Return piping from the collection header to the reliquefaction system is 6 inch stainless steel.

2.0 Insulation - In order to reduce the inleakage through the chamber walls to the liquid nitrogen heat sinks (approximately 14 $BTU/hr/ft^2$) reflective insulation is installed between the heat sink panels and the wall. The insulation consists of multiple layers of polished aluminum or aluminized plastic which reduces the inleakage to about 1 $BTU/hr/ft^2$.

3.0 Lunar Plane - The test article is supported on a vehicle mount described more fully in Section II-E. The upper surface of this mount constitutes the Lunar Plane and consists of an aluminum checkered plate floor approximately 45 ft in diameter and 1/2 in thick.

The upper surface of this floor is black anodized and the underside, to which are attached both cryogenic cooling circuits and electrical heating cables, is unfinished except for chemical cleaning after fabrication.

Pipes are welded to the underside of the Lunar Plane floor so that by circulating liquid nitrogen the temperature at the surface of the entire floor is lowered to about $100^{o}K$ and is controlled at this level. Between the liquid nitrogen cooled pipes electrical heating cable of the mineral insulated metal jacketed type is either clamped or welded to the underside of the plate. The heaters are supplied from 500 volt d-c silicon rectifiers to reduce the interference on adjacent instrumentation circuits. Voltage control equipment is furnished to permit varying the heating load from zero to 100% of rating.

When the Plane is being electrically heated, the cooling tubes are filled with gaseous nitrogen which is at the temperature of the Plane.

For either heating or cooling of the Lunar Plane, the entire floor is temperature controlled as one zone; however, temperature sensors are located at several points around the floor both under the test article near the center, and around the periphery. Any one of these temperature sensors can be used for controlling the temperature of the Lunar Plane.

Temperature control of the Lunar Plane is provided between approximately $100^{o}K$ and $120^{o}K$ and between $300^{o}K$ and $400^{o}K$. In the temperature range from $120^{o}K$ to $300^{o}K$ approximately, temperature control is not provided.

Both liquid nitrogen and electrical power is provided to the Lunar Plane through flexible connections on the underside of the platform.

Although the emergency repressurization openings which surround the Lunar Plane platform are at about the same level as the Lunar Plane, the louvered diffusers in the openings are cryogenically cooled only, and are not heated.

4.0 Cryopumps

4.1 Design - Twenty-two cryopump panels are supplied. Each panel consists of a helium circuit and a nitrogen circuit of 1 inch OD tubing, brazed or welded to 1/8 inch thick aluminum. The nitrogen circuit is used for cool-down. All surfaces of the cryopump panels are chemically cleaned for low emissivity. Panels are flat. Cryo pumping surface area is approximately 1,180 sq ft, and is installed between the lower and upper walkway levels.

4.2 Arrangement - Cryopump panels are arranged about the perimeter of the vessel on 6 ft centers in the area between upper and lower catwalks. Each panel is attached to its radiation shield with sufficient strength to support the weight of the panel, accumulated frost, and refrigerant. Sufficient freedom of movement is provided to allow for thermal contraction and support is provided to prevent undue flexing of the panels during rapid repressurization.

4.3 Heat Load - Calculated heat loads for the cryopump panels are as indicated in the following table:

HELIUM PANELS THERMAL LOADS *

		RADIATION		CONTINGENCY	TOTAL
		Direct	Reflected		
LUNAR LANDING					
400°K	13' x 40'	1.2	3.9	2.4	7.5
	25' x 75'	1.2	5.0	2.4	8.6
330°K	13' x 40'	1.2	2.7	2.4	6.3
	25' x 75'	1.2	5.0	2.4	8.6
EARTH ORBIT					
Top	13' x 40'	1.2	1.0	2.4	4.6
	25' x 75'	1.2	3.7	2.4	7.3
Side	13' x 40'	1.2	2.2	2.4	5.8
	25' x 75'	1.2	7.0	2.4	10.6

* Loads in Kilowatts

4.4 Helium Requirement - A 7-1/2 KW dense gas helium refrigeration plant is furnished.

4.5 Pumping Capability - The cryopump pumping rate is 2.7 lit/sec per cm^2. This has been determined from the array selected based on economics to provide the maximum molecular capture probability and the minimum heat gain.

4.6 Pressure and Operating Temperature - The cryopumps operate at a pressure of approximately 28 psig with an inlet temperature of 15°K and an outlet temperature of 20°K.

4.7 Control Zones - Each control zone is composed of approximately 200 sq ft of panel surface to accommodate a flow of 12 lbs per minute of dense gaseous helium. Approximately 8 zones are required. This will guarantee a heat pickup of 2.5 KW per zone which corresponds to a heat flux of 140 watts/ft^2 on the heat sink area.

4.8 Manifolding and Valves - Each zone is supplied from a 1 inch aluminum pipe and is discharged through a 1 inch aluminum pipe to a 3 inch stainless steel collection header. Supply and discharge piping to each zone penetrates the chamber wall. A temperature control valve is installed in the discharge piping from each zone to control the flow of refrigerant through each zone.

4.9 Supply Piping - Supply piping from the refrigeration plant to the distribution header is 3 in stainless steel pipe. Return piping from the collection header is 3 inch stainless steel.

SECTION II - C
VACUUM SYSTEMS

1.0 Gas Loads - The vacuum system is designed to attain an operating pressure level of 1×10^{-5} torr with the gas loads listed below. A 24 hour pumpdown capability from 760 torr to the operating level is provided.

a.	Extra vehicular suit (2)	5.0 torr lit/sec	100% oxygen
b.	Command module or lunar landing module	7.8 torr lit/sec	50% oxygen, 50% nitrogen
c.	Lunar propulsion allowance	1.0 torr lit/sec	100% nitrogen
		13.8 torr lit/sec	
d.	Virtual leakage from vehicles Actual leakage of facility Outgassing from vehicle surface	13.8 torr lit/sec	
	TOTAL	27.6 torr lit/sec	

2.0 Roughing System (Main Chamber)

2.1 General - The central main roughing system serving Chamber A or B will furnish the necessary pumping effort over the pressure range of 760 torr to 3×10^{-3} torr. It consists of a series of Roots Type, rotary, positive displacement pumps, cascaded in series, sized to provide the desired pumpdown rate and simultaneously handling the total design gas load.

The arrangement of the main pumping elements is shown on Fig. II-10. The contemplated valving, valve sizes, manifold interconnections and appropriate duct sizes are also shown.

A schematic arrangement of the roughing pump complex in relation to the test chamber is shown on Fig. II - 11.

A graphical presentation of the gas handling capacity of the system is shown on Fig. II - 12 and Fig. II - 13, which are "throughput" versus "suction pressure" curves for the cascade as well as individual stages.

Fig. II-14 illustrates an estimated "pressure" versus "time" curve of the system used to evacuate Chamber A.

2.2 System Description and Operation

2.2.1 Component Description and Operation - The cascade consists of two groups: A rough pumping group and a fine pumping group. The rough pumping group consists of three rotary positive vacuum boosters in series with intercoolers followed by a forepump stage. The individual boosters of this section are equipped with impellers constructed of cast iron and designed to operate at rotative speed such that the pitch line speeds of the timing gears will not exceed 3300 ft per minute. This section is called stage 2, stage 3, stage 4, and, for the forepump, stage 5. Intercoolers between the stages will remove the heat of compression to provide 100°F inlet temperature for the succeeding stage. The pumping speeds of the stages are such, that the ratio of pumping speeds will create compression ratios not exceeding the following:

Stage	Compression Ratio*
2	2.5
3	2.15
4	2.15

* This includes intercooler and piping pressure drop.

The nominal pumping speed of stage 2 is to be 9000 CFM. When stages 2 through 5 are used for rough pumping they exhaust directly from Chamber A (or B) through a rough pumping bypass connection. This is equipped with a throttle valve which automatically maintains 70 torr pressure at the inlet of stage 2 until the chamber pressure has fallen to 70 torr, below which the throttle valve will be wide open. The rough pumping system will continue pumping until the pressure at the inlet of stage 2 has fallen to 2 torr. At this pressure the valving will be changed and stage 1 will be started and operated ahead of, and in series with, stages 2, 3, 4, and 5 until the final chamber pressure of 3 microns is reached. Stage 1 consists of a motor driven vacuum booster, or boosters, having a nominal pumping speed of 40,000 CFM. The booster, or boosters, are equipped with modular iron impellers, and are designed to operate at a rotative speed such that the pitch line speed of the timing gears does not exceed 4600 ft per minute.

Stage 1 is not powered nor designed to operate at inlet pressures above 2 torr. Stage 1 also is followed by an intercooler; and, with the sizes as stated, will operate at a nominal compression ratio of 4.7.

The boosters of stages 1, 2, 3, and 4 are of the two-impeller (Roots) rotary positive type with one shaft above the other and with vertical flanges for horizontal pipe connection. Each blower is equipped with four face seals. The lubrication system is under atmospheric pressure. An integrally mounted oil pump with integral oil sump and oil cooler supplies cool oil under suitable pressure to the seals, bearings and timing gears. Before shipment, all units will be operated under load at the maximum temperature rise calculated for their service conditions; they also will be run blanked-off for a period of ten hours at an inlet pressure not exceeding 5×10^{-1} torr.

Stage 5 consists of "oil sealed" rotary piston type, gas ballasted, mechanical vacuum pumps affording a nominal capacity of 1000 CFM. Three pumps are connected in parallel to form this stage. Two 400 CFM and one 200CFMpumps are provided to give some flexibility and "stand by" capacity.

The intercoolers are designed to operate with 85°F cooling water, and will cool the air from the preceding stage down to 100°F. These coolers are sized to handle a peak cooling requirement for stage 1 (when it is receiving air at 2 torr) and for stages 2 to 4 (when stage 2 is receiving air at 70 torr).

The intercoolers are designed so that their pressure drop will not exceed 5 percent of the absolute pressure at their inlet The interconnecting piping between stages is of such size that its pressure drop will not exceed 2 percent, resulting in a total pressure drop of 7 percent between stages.

2.2.2 Special Considerations - The vacuum boosters and coolers with all parts (such as O-ring, etc.) are completely suitable for operating in an atmosphere of 100 percent oxygen. All parts will be resistant to oxygen "usable" lubricants such as cellulube, tricresyl phosphate, and halo-carbon. Before shipment, boosters and coolers will be cleaned of all hydrocarbons.

2.2.3 Connections & Piping - The duct sizes are largely influenced by the requirements of Chamber B, in accordance with the concept of a common central pumping facility for the entire Chamber A and B complex. The roughing header size is compatible with the maximum allowable pressure drop between the chamber and blower inlet when a chamber pressure of 3 microns exists.

With inlet pressure at the blower of 2×10^{-3} torr, the blower cascade will have a throughput of 25.8 torr lit/sec (See Fig. II-13) which equals

twice the basic leak of Chamber B. Since Chamber B must be at a pressure no higher than 3×10^{-3} torr when the Type A diffusion pump stations are valved into the chamber, the maximum pressure drop between blower inlet and chamber is 1×10^{-3} torr. (With 200 ft of manifold between pump and Chamber B, a manifold of 54 inches minimum diameter is used to meet the above conditions).

In the case of Chamber A, the 2 x L is 27.6 torr lit/sec and the manifold length is 40 ft, requiring a 36 inch diameter roughing connection.

The interconnecting piping between stages and between stages and intercoolers, as indicated on Fig. II-11, is designed so that pressure drops will not exceed 2 percent.

2.2.4 Valves

2.2.4.1 Main Roughing Valve - The main roughing valve in the duct to Chamber A, and the isolation valve ahead of stage 1 is of the air motor, solenoid pilot controlled, oblique shaft butterfly type with an inflatable seal to form a vacuum tight closure between the valve body and the butterfly disk in the closed position.

The selected valves are "Continental", T-ring sealed, butterfly valves or equal, using Teflon seal rings (such valves are manufactured by Continental Equipment Company, Coraopolis, Pa.). Both valves are 36 inch(nominal) in diameter.

2.2.4.2 Pressure Control Valve - The pressure control valve ahead of stages 2, 3, 4, & 5 is a 20 inch (nominal) diameter valve of similar construction to those described in 2.2.4.1, with a pressure controlled actuator to provide controlled throttling action in order to maintain the 70 torr suction pressure at the inlet of stage 2 of the blower cascade.

2.2 5 Utility Requirements

	MOTOR	WATER* GPM
Stage 1	150 HP	50 GPM
Interstage Cooler I		10 GPM
Stage 2	100 HP	20 GPM
Interstage Cooler II		31 GPM
Stage 3	100 HP	10 GPM
Interstage Cooler III		25 GPM
Stage 4	75 HP	7 GPM
Interstage Cooler IV		20 GPM
Stage 5	50 HP	15 GPM

* Water requirements based on a maximum ΔT - 15°F and a recommended inlet temperature of 85°F.

Compressed air at 100 psig, clean and lubricated is furnished for air cylinder operation of the valves.

Instrument air operates the controller of the 20 inch diameter Modulating Valve.

3.0 Diffusion Pump System

3.1 Diagrams and Graphical Data

Fig. II-15	Outline of Type A pumping station
Fig. II-16	Outline of Type B pumping station
Fig. II-17	Speed/pressure curve for Type A station
Fig. II-18	Speed/pressure curve for Type B station
Fig. II-19	Throughput/inlet pressure curve for Type A and Type B station
Fig. II-20	Estimated attainable pressure level with selected system versus total gas load
Fig. II-21	Schematic layout of pumping system

3.2 General - The pumping system consists of 14 diffusion pumping stations (4 - 32 inch Type A and 10 - 35 inch Type B) effecting pumpdown to 1 x 10^{-4} torr (at which 1180 sq ft of cryopumping surface at 20°K becomes operative).

The combination of these pumping devices results in an estimated, attainable pressure level of 1 x 10^{-5} torr with a total "leakage" load of 27.6 torr lit/sec. (Fig. II-20)

3.3 System Description and Operation

3.3.1 Pumping Station Performance - Performance curves for individual pumps and pumping stations are shown on Fig. II-17 and Fig. II [illegible] Data plotted are:

a. Unbaffled: Speed vs inlet pressure at the pump
b. Effective: Speed at inlet to station vs pressure at inlet to station.

These curves are based on the use of standard heater ratings. DC 704 Silicone operating fluid and the water-cooled valve and transition piece configuration shown on Fig. II-15 and Fig. II-16.

Fig. II-19 shows curves of individual pumping station throughput versus inlet pressure to the pumping station for the applicable range of operation.

3.3.2 Component Selection - The valves are air-hydraulically actuated and are constructed to effect "emergency" closure in about seconds. The valve body is water-cooled and may contain a minor "eyelid" baffle. The inlet duct is inclined about 5^{o} from the horizontal for return of any accumulations of oil vapor droplets over protracted operating periods.

The transition piece between valve and pump also is water-cooled and is sized to accept a water-cooled baffle for future capability upgrading. (Ref. Para. 3.4)

The cooling water temperature for valve and baffle will be as low as possible, probably 80°F or less (Refer to Vapor Pressure - Temperature Curves of Pump Fluids). If water is not available at sufficiently low temperatures, consideration will be given to the use of a chiller (or heat exhanger with the LN_2 gas of the facility). The quantity of water depends on the temperature, but will be of the order of 5 GPM per valve and transition piece assembly.

3.3.3 Pump Fluid - The fluid is Dow Corning DC 704 Monsanto OS-124, or equal.

3.3.4 Utility Requirements

a. Electrical
   1. Heater Rating of Type A station — 24 KW
   2. Heater Rating of Type B station — 16 KW
   (Electrical characteristics 220/440 volt, 3 phase, 60 cycle)

b. Cooling Water (clean, filtered)
   1. 48 inch valve and transition piece estimated at inlet temperature as low as practical (See Note above) — 5 GPM
   2. Type A station diffusion pump at 60°F to 80°F inlet — 4 GPM
   3. Type B station diffusion pump at 60°F to 80°F — 3 GPM

NOTE: Allowance will be made for higher inlet temperature and consequent increase in the flow required.

c. Other

1. Air-Hydraulic Actuating System for 48 inch valves
   Capacity to be determined. Desired valve closure time and pressure differential when a pump is removed for servicing, dictate a high pressure hydraulic system with about 2000 psig rating and a 4 to 5 inch actuating cylinder per valve.

2. Compressed Air (100 psig clean-filtered, oiled)
   For actuation of all other system valves (forelines, air bleed, etc.)

3.3.5 System Description

a. Facility layout, Fig. II-2, shows the physical arrangement of the 14 pumping stations in relation to the test chamber. The pump stations are arranged in 3 tiers. The 48 inch inlet ducts are welded directly to the chamber shell. The arrangement is schematically shown on Fig. II-22. The selected arrangement permits minimum lengths of backing and foreline connections with resulting maximum efficiency for the assembly.

b. The interconnecting manifolding between the individually valved pump station foreline connections and the backing pump system, elsewhere described, consist of three 10 inch diameter partial ring mains joined to a 12 inch verticle header. The header is connected through a 14 inch diameter pipe run to the inlet of the backing pump assembly.

3.3.6 Operation - The pumping stations will be made operational at a predetermined time interval after commencement of rough pumping. When a chamber pressure of 3×10^{-3} torr is reached, they will be ready to be placed "on stream". At this pressure level, the 4 Type A stations will be placed "on stream" by opening the respective 48 inch inlet duct valves.

Below pressures of 8×10^{-4} torr, stations Type B will be sequentially placed on stream by a similar procedure, balancing the maximum backing pump capacity against the throughput of the total number of connected diffusion pump stations.

3.4 Upgrading Provisions - The performance of the diffusion pumps can be upgraded for operation at lower than previously attainable, or specified, pressure levels by replacing the "transition pieces" (between the valve and pump of the pumping stations) with a liquid nitrogen cooled baffle of suitable design and/or the use of a higher grade pump fluid such as Dow Corning XF-4660. Alternatively the transition piece can be modified to act as such a baffle.

4.0 Backing Pump System

4.1 Selection and Description - The backing system required for the satisfactory operation of the diffusion pump complex described in Section 3.3, is sized to afford maximum capacity operation of all 14 pumps at chamber pressure levels below 8×10^{-4} torr and for the 4 Type A stations at higher levels (3×10^{-3} torr and below).

It is a 2 stage cascade consisting of a 2000 CFM Roots type positive displacement blower backed by a 200 CFM "oil sealed" rotary piston, gas ballasted mechanical vacuum pump.

The system uses oxygen-"usable" sealants and pump fluids. It is connected to the main 12 inch backing header which gathers the gas handled by the diffusion pump via the 3-ring, foreline headers.

4.2 Utility Requirements

	HP	Cooling Water
2000 CFM Blower	20	12 GPM
200 CFM Mechanical Pump	10	- -

5.0 Personnel Lock Pumping System

5.1 Selection and Description - The pumping system consists of a 5000 CFM, positive displacement first stage blower, backed by a 1000 CFM blower stage which discharges into a 200 CFM "oil sealed" rotary piston, gas ballasted, mechanical vacuum pump. The cascade system uses oxygen-"usable" sealants and pump fluids.

A 16 inch isolation and throttle valve of butterfly design with inflatable T-seal (Continental or equal) is provided between the suction of the first stage and the personnel lock it serves.

The cascade system will be mounted as close to the lock as possible, or adequately sized manifolding to insure a minimal pressure drop will be provided.

The system will provide personnel lock pressures in the 3×10^{-3} torr range with a "leak" of 5 torr lit/sec (2 suits).

5.2 Utility Requirements

		HP	Cooling Water
a.	5000 CFM Blower	25	15 GPM
	1000 CFM Blower	10	2 GPM
	200 CFM Mechanical Pump	10	- -

b. Compressed air at 100 psig, clean and lubricated, provided for valve actuation.

6.0 Cryopumps (Refer to Section II-B)

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SECTION II - D
SOLAR SIMULATOR

1.0 Module Description - Two modular solar simulator designs are used in Chamber A.

a. A side chamber illuminating module which can be used for both the side solar flux and for earth albedo flux.

b. A top illuminating module which will be used for providing the overhead solar flux.

1.1 Side Module Description - Fig. II-23 shows the general layout of the proposed side module. The overall size of the module is approximately 57 inches high x 52 inches wide and 61 inches deep. The rear top portion of the module is sloped in order to provide access to the lamps and associated equipment of the module above it.

1.1.1 Lamp - Collector Assembly - Each module is capable of containing a maximum array of seven 5 kw high pressure Xenon arc lamps. Each lamp is contained in a lamp housing assembly consisting of an ellipsoidal primary collector reflecting mirror approximately 16 inches in diameter and having a focal length of approximately 60 inches. A secondary collector mirror, hemispherical in shape, is placed opposite the primary reflector in such a position as to redirect the radiant energy, being emitted upward from the lamp, back to the focal point of the primary reflector. The secondary collector serves to intensify the light beam at the focal point of the primary collector and thus increase the collection efficiency of the system.

Due to the localized high energy intensity in the lamp assembly area, forced air cooling of both the primary collector and the secondary reflector is provided. The lamp will be similar and equal to the General Electric 5 KW DC Xenon compact-arc lamp. This lamp offers high energy collection efficiency because of the compactness of its arc. Forced air cooling provisions (2 psi) are provided for the lamp stems.

1.1.2 Lamp Deck Assembly - Each lamp-collector assembly is prefocused and rigidly fastened onto a lamp deck which also serves to support the auxiliary equipment necessary for the proper operation of the lamps. This includes the lamp igniters, air cooling manifolds or ducts, electrical cabling and mechanical support hardware.

As previously stated, the rear portion of the module is sloped to provide access to the underside of the lamps and associated equipment of the module above. To permit replacement of lamps at the far end or chamber side, (Fig. II-23) the entire lamp deck is rotatable through a limited angle. This feature permits lamp replacement without shutting down and without removal of the entire module from service.

1.1.3 Flat Reflecting Mirror - The light energy transmitted by the lamp collector array is directed to a large stainless steel mirror which redirects the light beam to the optical system which is contained in a window lens assembly located on the chamber wall.

1.1.4 Module Cooling - Attached to the rigid framework of the module are water cooled panels for absorbing the radiated and reflected energy from the lamps which is not directed through the optical system.

1.2 Top Module - Fig. II-24 shows the general layout of the overhead solar module. General construction of the module is similar to that of the side oriented module. The lamp collector assemblies are mounted on the top portion of the module. A stationary deck assembly can be used as all the lamps will be accessible from the top of the module.

As the light beam is oriented downward, the top module does not require an intermediate reflecting mirror. In order to achieve the proper focal length the module will be approximately 77 inches high. Provisions for forced air cooling and water cooling of module walls are similar to requirements for the side modules. The module is provided with leveling means for properly orienting and focusing the light beam on the optical window lens assembly. Provisions for securing the module rigidly in place after alignment also will be provided.

2.0 Window Lens Assembly - The radiant light energy from the module is directed to a window lens assembly which is permanently fastened to the chamber wall. Tentatively, the window lens optical array consists of a 6 inch free aperture relay lens, a 15 inch free aperture collimator lens and a 15 inch multiple faceted projection lens. As the chamber is to be man-rated, a plane window is provided as the last element in the system as a safety precaution.

Fig. II-25 shows a general layout of the window lens array and its relationship to the chamber wall and light source module. Vacuum seal provision is provided between the optical elements and the lens assembly housing.

Enclosing the entire lens assembly in its own housing permits pre-assembly and check-out of the entire lens array prior to installation in the chamber. The lens assembly is mounted to the chamber through a gasketed flanged sleeve penetration into the chamber wall, which arrangement simplifies the installation and removal of the window lens assembly. Additional flanged penetration ports in the chamber at appropriate spacings permit the solar and albedo features of the chamber to be expanded at a future date without changes to the chamber wall. A number of these additional penetrations can be equipped with viewing ports as shown on Fig. II-25.

The function of the basic module can be changed by altering the lens configuration. For example, a slight modification of the optical system will convert a side sun simulator module into an albedo simulator module. This feature provides a system with maximum flexibility and a minimum number of dissimilar parts.

3.0 Varying Flux Intensity - The intensity of the lamps is varied by shutting down lamps and/or decreasing the output from each lamp. The 5 KW can be operated at a half-intensity.

4.0 System Performance

4.1 Intensity of Illumination - The mean illumination level over the projected target area is variable from 25 watts/sq ft to a maximum of 140 watts/sq ft.

4.2 Spectrum - The spectrum distribution from a 5 KW Xenon high-pressure arc lamp, as modified by the optics in the system is shown in Fig. II-26.

5.0 Module Arrangement (See Figs. II-27 and II-28)

5.1 Side Sun - In order to irradiate a target area of 13 x 40 ft, 18 side modules are used, arranged in two vertical stacks of nine each. Thus, each module irradiates an area approximately 5 ft high and 6 1/2 ft wide. The modules are arranged on five foot centers, both vertically and horizontally.

5.2 Top Sun - Four top modules are provided for irradiating an area 13 ft in diameter.

5.3 Albedo - In order to irradiate the 13 x 40 ft target area a single stack of nine modules mounted 180° away from the solar simulator source are provided.

6.0 Upgrading Provisions

6.1 Increase in Vehicle Size - To accommodate future growth of Chamber A to a vehicle size of 25 ft diameter and 75 ft long, additional flanged ports are incorporated in the chamber wall as described in Section 2.0. The side solar simulator will require the addition of 46 ports spaced in 5 ft centers, as shown on Figs. II-27 & II-28 to accommodate the expanded 25 x 75 ft test area. The top sun will be expanded to accommodate a total of 21 modules on five foot centers as shown on Fig. II-27.

For expansion of the albedo radiation to the larger target area, two vertical rows of ports stacked 16 high on 5 ft centers, approximately 35° from the original albedo ports, will have to be added as shown on Figs. II-27 and II-28. The original albedo ports not needed for the albedo radiation may be used as observation ports as desired.

6.2 Solar Spectrum - With the addition of appropriate filters in the light beam and the use of a Mercury- Xenon and Xenon lamp mixtures, it will be possible, at a future date, if desired, to upgrade the solar system so that it more closely coincides with the actual spectrum.

7.0 Power Supplies - For flexibility in the operation and control of short arc type lamps, either a solid state power supply or motor generator set to power each individual lamp will be provided.

A commerically available solid state power supply that may be used to power the 5 KW Xenon lamps is the Westinghouse 12.6 KW short-arc silicon rectifier power supply (Type WS). Nominal primary input voltage is 460 volt, 3 phase, 60 cycle A. C. The approximate physical size of this power supply is 24 inches wide, 24 inches deep and 30 inches high.

8.0 Service Requirements

8.1 Electrical - Table I indicates the overall power requirements for both the present and future Chamber A configurations.

It should be noted that power to the lamps does not include conversion losses of the power supply. Power supply efficiency is approximately 80 percent.

8.2 Cooling

8.2.1 Air Cooling - It is estimated that approximately 560 CFM of air will be required to cool each 7-lamp array module.

8.2.2 Water Cooling - As previously stated, each module will contain water cooled panels. Cooling water requirements per module are estimated at 20 gallons/minute with an anticipated $8^{o}F$ temperature rise.

9.0 Heat Load into Chamber - Table I illustrates the anticipated chamber heat loads caused by the lamps for both the present and future Chamber A configurations.

TABLE I

SUN & ALBEDO SIMULATOR - HEAT AND POWER LOADS

CHAMBER A

PRESENT CONFIGURATION (13' x 40' Test Area)	No. of Modules	Chamber Heat Load(KW)	Power To Lamps(KW)	External Cooling(KW)
Side Sun	18	95	630	535
Top Sun	4	21	140	119
Albedo	9	48	315	267
EXPANDED CONFIGURATION (25' x 75' Test Area)				
Side Sun	64	336	2240	1905
Top Sun	21	95	630	535
Albedo	32	168	1120	952

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SECTION II - E
VEHICLE MOUNT AND HANDLING

1.0 Vehicle Mount - The vehicle mount is a turntable 45 ft in diameter driven by a 40 HP electric motor.(See Fig. II-29) The motor speed is reduced through a reversible gear driven transmission to provide a turntable speed variable between 1/6 RPM and 1 2/3RPM. The output of the reducer is connected through a pinion gear to an internal ring gear about 80 inches in diameter and attached to the turntable. (See Fig. II-31) The limits of rotation are 180° in either direction (0° to 360°). The rotation of the table can be stopped within ± 5 ° of a selected point. Fig. II-32 correlates the acceleration and deceleration with the rotational speed.

The turntable frame consists of 8 main members separated radially by an angle of 45°. (See Fig. II-30). These members are of rolled channel section, 20 inches deep so that each of the 8 pieces of the octagonal frame can be fabricated and shipped separately. The 8 main members are supported at the center by a thrust bearing and by wheels which ride in a 37 ft diameter circular track. Any four of these members will support a concentrated load of 25,000 lbs (one fourth the weight of the test article) applied at any radius between 6 1/2 ft and 20 ft. Deck plating and intermediate framing is designed for 100 lbs/ft^2. The turntable floor is constructed of 1/2 inch aluminum plate in sections. The floor plate sections are designed to allow ample space for expansion and contraction during the temperature excursions it will encounter.

The checkered plate aluminum deck of the turntable is a liquid nitrogen cooled black heat sink. The liquid nitrogen is supplied to tubes on the underside of the plate via a flexible connection. Strip heaters are also attached to the underside of the plate for providing lunar plane temperature (Refer to Section II-B).

An opening 24 inches in diameter is provided in the center of the table for vehicle power, communications, and instrumentation leads

A determination of whether the electric motor and gear reducer must be heated and/or cooled will be made during the detail design phase.

A manually operated table lock is provided to facilitate locking the table in the vehicle loading position. Operating procedures will be provided which will guard against the possibility of the table being left in the locked position after loading the chamber and starting the roughing pumps.

The mount lubrication will be suitable for use at the design vacuum levels and will be oxygen compatible.

2.0 Vehicle Handling - The sequence required for installation of the maximum size vehicle is illustrated by Fig. II-33 and consists of the following steps.

a. Load uppermost module onto dolly and bring into chamber.
b. Lift module with chamber roof hoists, remove dolly.
c. Load intermediate module onto dolly, and bring into chamber.
d. Lower uppermost module and connect to module on dolly.
e. Raise combined modules with chamber hoists and remove dolly.
f. Load last (lowest) module onto dolly, bring into chamber.
g. Lower combined module and connect to module on dolly.
h. Raise total combined vehicle, remove dolly and position vehicle for test.
i. Install test accessories, remove hoists and temporary equipment, close chamber door.

SECTION II-F
REPRESSURIZATION SYSTEM

1.0 General - Two separate and independent systems are provided for repressurizing the chamber. Routine repressurization is accomplished by means of the normal chamber repressurization system. Extremely rapid chamber repressurizations, which may be necessary in order to effect astronaut recovery in an emergency, are accomplished by the emergency system.

The only feature common to both systems is the repressurization air plenum and distribution baffles installed within the space chamber and located around the periphery of the lunar platform. This plenum contains impact plates, distribution baffles and air outlet diffusers all of which are designed to insure that the repressurization air enters evenly around the chamber at the floor level. This plenum is shown on Fig. II-2 and is discussed further under Emergency Repressurization System.

2.0 Normal Repressurization System - Prior to admitting air to the evacuated chamber in which the heat sink walls have been cooled to cryogenic temperatures, it normally will be desirable to have warmed all the inner surfaces by circulating heated nitrogen gas. A period of several hours may be required to increase the average temperature of the surfaces within the chamber to above the dew point temperature of the repressurization air.

Admission of nitrogen gas prior to repressurization has been found advantageous on other large space chambers as a means for reducing subsequent pump-down times even when the nitrogen gas pressures are quite low. Consequently, means are provided on this chamber for introducing gaseous nitrogen as the first stage of normal repressurization. The chamber pressure is raised to 0.5 microns with nitrogen gas. This is adequate to obtain all the advantages on the succeeding pump-down that nitrogen can provide.

Air used for normal repressurization will be taken from outside the building, passed through dry air filters and dehumidified as required to obtain an inlet temperature to the chamber of about 75°F DB, with a 50% R.H. The dehumidifying equipment is designed to handle the air mass required to repressurize the chamber to atmospheric pressure in a period of approximately 3 hours.

The normal repressurization system is designed so that it can be used, rather than the emergency system, to obtain a fairly rapid rate of repressurization when it is necessary to do so even though the heat sinks are at cryogenic temperatures and cannot be warmed in the time allowed for the pressure rise. This rate of pressure rise is from vacuum to 5 psia in a 30-minute period. Inlet filters are provided for this condition.

All normal repressurization air is admitted through one butterfly type valve approximately 2 ft in diameter. This valve is pneumatically operated and equipped with throttling control action regulators so that it can be used as either a flow regulator or a pressure regulator. This valve is of the inflatable seal type as described in Section II-C.

3.0 Emergency Repressurization System

3.1 General - In order for the chamber to be considered man rated, it is necessary to provide means for its partial repressurization at extremely rapid rates. In addition to the rapid increase in total pressure required within the chamber, it is also necessary that certain minimum partial pressures of oxygen gas in the mixture introduced into the chamber be attained during the initial repressurization period.

The emergency repressurization system is designed to achieve the following partial and total pressure levels within the times indicated. A more complete discussion of these criteria is included in Section IX.

a) Obtain 1.0 psia within 10 seconds after injection valve actuation. - total pressure

b) Obtain 1.6 psia within 30 seconds. - oxygen partial pressure

c) Obtain 2.5 psia within 45 seconds. - oxygen partial pressure

d) Automatic repressurization not to exceed 5.0 psia $\pm$ 1/2 psi.

e) Dynamic pressures on objects within the chamber proper should be less than 15 pounds per square foot.

3.2 Description - The emergency repressurization system utilizes both atmospheric air and stored high pressure gaseous oxygen to obtain the required oxygen partial pressures and total pressures within the prescribed time limits.

Atmospheric air is drawn into the chamber through large fixed dry filters, (located outside the chamber building,) suction pipes and four convergent-divergent nozzles. These nozzles discharge through the wall of the chamber into a plenum as indicated on Fig. II-30.

Gaseous oxygen stored at about 2400 psi is used to enrich the air so that the resulting mixture at the end of about 30 seconds is 50 percent oxygen. This gas is injected into the air lines just ahead of each of the four convergent-divergent nozzle throats.

The primary air admission valves are located in the throat of each of the nozzles. These valves are of the inflatable seal-butterfly design and are more fully described in Section II-C.

The oxygen injection valves are interlocked with the air admission valves so that they are not energized until 5 seconds after actuation of the air valves at which time the air valves will be open. A position switch insures that the oxygen valves do not unless the air valves are fully opened.

When the chamber pressure has risen to 5.0 psia three of the four main air valves close and the fourth air valve commences modulating to control the chamber pressure at 5 psia $\pm$ 1/2 psi.

A convergent-divergent or DeLaval nozzle is employed to introduce both the air and the oxygen into the chamber distribution plenum. The convergent nozzle design yields the highest possible flow coefficient thus minimizing the required flow area of the valves, and the divergent passage is required in order to obtain a smooth expansion to a pressure less than the critical pressure. Although the exit velocity and kinetic energy of the gas leaving the nozzles are well above that which would be obtained with an orifice type of opening into the chamber, the resulting pressure entering the plenum is considerably lower.

The resulting supersonic gas velocities are reduced and the kinetic energy is transformed into thermal energy within the plenum, as the result of internal turbulance, (which takes place as the gas expands and deccelerates), impact of the stream on the impact baffles, and the expansion through multiple orifices located within the plenum. Thus, gas velocities entering the chamber proper do not exceed sonic speeds.

The mixture of air and oxygen enters the chamber proper through diffusers which are located around the periphery of the turntable as

indicated on Fig. II-30. About 550 sq ft of opening area is provided for Chamber A. The pressure of the gas entering the chamber is very low (on the order of 0.10 psia) so that even with the sonic velocity, which results as the gas expands through the diffusers, the total impact pressure is less than 15 psf.

SECTION III-A
VESSEL

1.0 Size, Shape and Orientation - The vessel is shown on Fig. III-2. It consists of a 35 ft diameter vertical cylinder with a removable flanged D/3 ellipsoidal top head and a permanently attached D/3 ellipsoidal bottom head. The overall height of the vessel is 43'-4". The lower tangent line is located at main floor level.

2.0 General Structural Details

2.1 Plate and Stiffeners - The shell and heads for the chamber are calculated to have the same factor of safety in the plate (approx. 2.5) as an unstiffened sphere designed by ASME Code procedures. The factor of safety for the stiffeners is approximately 3 against ring instability. Designing to these criteria, the plate thicknesses, stiffener sections, and maximum stiffener spacing should be approximately as follows:

	Plate "t"	Stiffeners	Max. Spacing
Top and Bottom Heads	.44 "	7 x 4 x 3/8 Ls	40"
Cylindrical Shell	.48 "	9 x 4 x 3/4 Ls	38"

2.2 Vehicle Access Opening - Test vehicle access is provided by the removable top head. The rolling bridge crane operating in the building crane bay will remove the head, place or remove the test vehicle and then replace the head.

The mating flanges for the head and cylinder are stiffened adequately to prevent deflection and warping which could ruin the sealing capability. The proposed method for attaining the required stiffness is shown on the chamber drawing, Fig. III-2.

2.3 Supports - This chamber is supported by four 12 in wide flange structural columns uniformly spaced around the periphery and attached to the bottom head near the lower tangent line.

3.0 Material and Finish - The material for this chamber is the same as for Chamber A - that is, plate nozzles and internal structural elements are AISI Type 304 with normal mill finish.

The stiffeners and external structural elements are structural quality carbon steel.

4.0 Personnel Locks - One double manlock provides personnel access to the chamber from the main floor of the building. Details of this lock are shown on Fig. II-5. The lock, shell and doors, excepting the doors through the chamber wall, are constructed of carbon steel.

The comments in section II-A apply to this lock also.

5.0 Personnel Access (Internal) - Personnel can enter the chamber at the double lock at elevation /23 which is at the level of the vehicle support platform. The vehicle support platform and the annular grating platform provide personnel access over the entire chamber within the heat sink walls at elevation /23. It is contemplated that ladders will be used for vertical access on the test vehicle exterior.

6.0 Penetrations - Vessel penetrations are required for vacuum pumps, cryogenic piping, solar simulator ports, electrical and instrumentation lines, viewing ports, umbilical connections to space suits and repressurization inlets.

a. Vacuum Pump Penetrations - Twelve 48-inch diameter nozzles are provided in the cylindrical portion of the vessel for connection to diffusion pumps. One 54-inch diameter nozzle is provided in the bottom head for connection to the roughing pump system.

b. Cryogenic Penetrations -For liquid nitrogen supply and return lines, fourteen 6-inch diameter penetrations are provided.

c. Solar Simulator Ports - In the vessel head, five 18-inch diameter solar simulator ports are provided, the center one being for initial installation and the other four for future installation. In the cylindrical portion of the vessel, twelve 18-inch diameter solar simulator ports are provided, all of which are for future installation. The ports provided for future additions are blanked off with stainless steel vacuum tight caps or view port assemblies.

d. Electrical and Instrumentation Penetrations - Multiple electrical instrumentation penetrations, located at the base of the chamber, are sealed in sleeves which are mounted in a flange plate. This assembly can be shop tested for vacuum tightness before installation and welded or bolted into a shell penetration without damage to the vacuum seal.

Electrical power penetrations consist of hermetically sealed bulkhead fittings on shop assembled and shop tested panels which are welded to the vessel wall. These penetrations are located at the base of the chamber for the lunar plane heaters. Light duty power penetrations for the internal illumination of the chamber are located on the top head.

e. Viewing Port Penetrations - Penetrations are provided in the chamber and lock walls for 10-inch diameter viewing ports required for visual surveillance of locks and chamber during test operation. At the double lock nine viewing ports are provided, located identically to those in the Chamber A double lock as shown on Fig. III-2.

In addition to the viewing ports associated with the locks, four viewing ports are provided in the chamber above the ground floor level and four in the future simulator ports in the top head.

f. Umbilical Penetrations - For umbilical connections for space suited personnel within the locks or chamber, 10-inch diameter penetrations are provided. There are three such penetrations in each lock and five around the chamber wall at the lunar plane level. The services which feed through the umbilical connections are described in Section IX.

g. Repressurization Penetrations - Four 12-inch diameter nozzles are provided in the bottom head for emergency repressurization and one additional 12-inch diameter nozzle is provided for normal repressurization.

7.0 Ventilation - Ventilation of Chamber B is provided for personnel working on the test article while the top head is installed. The system will be similar to Chamber A described in Section II-A.

8.0 Upgrading - The vessel is designed so that an additional 10-12 feet of chamber height can be obtained in the future by inserting a structural ring of the required depth between the present head and vessel top flange. An additional man lock and access platform can then be established at the upper level. Additional solar simulator units can be installed in the new ring. The fixed mount presently provided is designed for vehicles weighing 40,000 lb and is arranged so that it can be converted to a rotary mount.

With these provisions the chamber can be upgraded to handle the 13 foot diameter by 24 feet high test article.

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SECTION III-B
CRYO-ARRAYS

1.0 Thermal Loads - Calculated thermal loads for the heat sinks are as follows:

Heat Sink Thermal Loads (Kilowatts)

	Lunar Landing			
Operating Temperature	400°K		330°K	
Target	25 sq ft	13' by 24'	—	13' by 24'
Heat Leak	6	6	—	6
Vehicle	4	4	—	4
Solar Simulator	5.25	21	—	40
Lunar Plane	63	63	—	30
Sub Total	78.25	94		80
Pump Work	4.75	6		5
Total	83	100		85

	Earth Orbit			
	Side Sun		Top Sun	
Target	—	13' by 24'	25 sq ft	13' by 24'
Heat Leaks	—	8	8	8
Vehicle	—	4	4	4
Solar Simulator	—	56	5.25	21
Lunar Plane	—	-	-	-
Sub Total		68	17.25	33
Pump Work		4	1.75	2
Total		72	19	35

2.0 Nitrogen Requirements - Nitrogen requirements are supplied by the 280 KW nitrogen reliquefaction plant as specified for Chamber A.

3.0 Panel Design and Arrangement - The heat sink panels are similar in design to the heat sink and thermal shield panels used in Chamber A. (Fig. II-8) It should be noted that no helium cryopumping panels are installed in Chamber B. One row of rectangular vertical heat sink panels 20 ft in length are arranged about the perimeter of the vessel. These panels present an area of approximately 1760 sq ft. Heat sink panels for the dished head of the chamber are trapezoidal in shape, arranged in a ring between the vertical panels and the solar top plate. These panels present an area of approximately 720 sq ft. The top plate is similar to the top plate in Chamber A and is approximately 78 sq ft in area. All penetrations of the heat sink, such as the solar lens openings, are shielded the same way as Chamber A. An overall view of the heat sink panels is shown on Fig. III-3.

4.0 Pressure and Operating Temperature - The heat sink operates under the same conditions as Chamber A.

5.0 Control Zones - Approximately seven zones are required. These are similar to zones of Chamber A.

6.0 Manifolding and Valves - These are similar to Chamber A except the main headers are 2 -1/2 inch stainless steel.

7.0 Supply Piping - Supply piping from the reliquefaction plant to the zone headers is 2-1/2 inch stainless steel pipe. Return piping is 2-1/2 inch stainless steel and connects to the six inch return line of Chamber A.

8.0 Insulation - Insulation is provided on the exterior face of the heat sink panels in the same manner as Chamber A.

9.0 Lunar Plane - The lunar plane in Chamber B is similar to the plane in Chamber A except that it does not rotate and thus the connections can be made rigid rather than flexible. The diameter is approximately 16 ft.

SECTION III-C
VACUUM SYSTEMS

1.0 Gas Loads - The vacuum system will attain an operating pressure level of 1×10^{-4} torr handling the gas loads detailed below. A 3-hour pumpdown capability from 760 torr is provided.

a.	Extra vehicular suit (2)	5.0 torr lit/sec	100% oxygen
b.	Command & Lunar Landings module	7.8 torr lit/sec	50% oxygen 50% nitrogen
		12.8 torr lit/sec	
c.	Virtual leakage from vehicle Outgassing from vehicle surface Actual leakage of facility	12.8 torr lit/sec	
	TOTAL	25.6 torr lit/sec	

2.0 Roughing System (Main Chamber B)

2.1 General - The central main roughing system provided will furnish the necessary pumping effort over the pressure range of 760 torr to 3×10^{-3} torr.

It consists of the system described in Section II-C-2.0. Fig. III-3 is an estimated "pressure versus time" curve based on using this system to evacuate Chamber B. The operation of the roughing system is as described for Chamber A.

2.2 Connections & Piping - The duct sizes are based primarily on the requirements of Chamber B, considering that a common central pumping facility for the the entire Chamber A plus B complex is furnished. The roughing header size is compatible with the maximum allowable pressure drop between the chamber and blower inlet when the chamber pressure is 3 microns.

With inlet pressure at the blower of 2×10^{-3} torr, the blower cascade will have a throughput of 25.8 torr l/s (Fig. II-14). This will be capable of handling twice the basic "leak" of Chamber B (25.8 torr lit/sec). Since Chamber B must be at a pressure no higher than

3×10^{-3} torr when Type A diffusion pump stations are valved into the chamber, the maximum pressure drop between the blower inlet and the chamber is 1×10^{-3} torr. (To meet the above conditions with a manifold length of 200 feet (approx) between pump and Chamber B, the minimum manifold diameter is 54 inches.) Interconnecting piping between stages and between stages and intercoolers, as indicated on Fig. II-11, is designed so that pressure drops will not exceed 2 percent.

2.3 Valves - The main roughing valve in the duct to Chamber B and the isolation valve ahead of Stage I are of an air-motor, solenoid pilot controlled, oblique shaft butterfly type with an inflatable seal to form a vacuum tight closure between the valve body and the butterfly disk in the closed position. The selected valves are "Continental" T ring sealed butterfly valves or equal, using teflon seal rings. The valve in the main roughing duct is a 54 inch diameter nominal size.

3.0 Diffusion Pump System

3.1 General - The pumping system consists of 12 diffusion pump stations (4-32 inch Type A and 8-35 inch Type B) effecting a pumpdown to 1×10^{-4} torr (using diffusion pumps only; no cryopumps are to be provided).

The maximum total gas load for the attainable pressure level of 1×10^{-4} torr is taken to be 25.6 torr liters/sec. (Fig. III-4).

3.2 System Description and Operation

3.2.1 General - The Type A and B diffusion pumps stations are the same as those described for Chamber A. The performance is illustrated in Fig. II-17 and II-18. The pump fluid and utility requirements are the same as Chamber A.

3.2.2 System Description

Facility layout drawing Fig. III-1 shows the physical arrangement of the 12 pumping stations in relation to the test chamber. The pump stations are arranged in 2 blocks of 6 each located at 2 levels, and the 48 inch inlet ducts are welded directly to the chamber shell. The arrangement is schematically shown on Fig. II-22.

The selected arrangement permits minimum lengths of backing and foreline connections, resulting in maximum efficiency for the assembly.

The interconnecting manifolding between the individually valved pump station foreline connections of each block of 6 pumps and their backing pump system, elsewhere described, will consist of 10 inch diameter pipe mains. These mains connect through 10 inch links to 12 inch headers. Each header is connected to the inlet of its appropriate backing pump assembly.

3.2.3 Operation - The operation of the pump stations is the same as described for Chamber A in Section II-C-3.3.6.

3.2.4 Upgrading Provisions - The upgrading provisions are the same as for Chamber A described in Section II-C-3.4. In addition, space on the chamber surface permits adding six diffusion pumps in the future.

4.0 Backing Pump System

4.1 Selection and Description - The backing system required for the satisfactory operation of the diffusion pump complex described in Section 3.2.2 is sized for maximum capacity operation of all 12 pumps at pressure levels below 8×10^{-4} torr and for the 4 type A stations at higher levels (3×10^{-3} torr and below).

It consists of two identical pumping systems, each serving a "block" of 6 diffusion pumps. Each system consists of a two-stage cascade including a 1000 cfm Roots Type positive displacement blower first stage backed by a 100 cfm "oil sealed" rotary piston, gas ballasted, mechanical vacuum pump.

Each system utilizes oxygen "usable" sealants and pump fluids. It is connected to the main 12 inch backing line which collects the gas from one block of six diffusion pumps through the foreline headers and links previously described.

4.2 Utility Requirements

Each Unit	HP	Cooling Water
1000 cfm blower	10	6 gpm
100 cfm Mechanical Pump	5	- - -

5.0 Personnel Lock Pumping System - The lock pumping system is the same as for Chamber A described in Section II-C-5.0.

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SECTION III - D
SOLAR SIMULATOR

1.0 General Description - The solar simulation module optical characteristics and associated systems are the same as those described for Chamber A in Section II-D.

2.0 Module Arrangement (See Fig. III-6)

2.1 Present Configuration - Chamber B is equipped with a single top illuminating module which will irradiate an area of approximately 25 sq ft on the floor of the chamber. This top module is identical to those proposed for Chamber A. Some modifications to the window lens optics will be required to properly irradiate the specified test area.

3.0 Upgrading Provisions

3.1 Top Sun - In order to expand the system to irradiate the top of a future test article 13 ft in diameter and 24 ft high, four additional flanged ports, as indicated on Fig. III-6, are provided.

3.2 Side Sun - Twelve flanged ports are provided for future installation of side solar simulators. These ports are arranged in four horizontal rows of three each as shown on Fig. III-6. It is anticipated that only five lamps will be required in the future side modules to provide 140 watts/ft^2.

4.0 Service Requirements - Service requirements are similar to Chamber A and are illustrated in detail in Table I.

5.0 Heat Load into Chamber - Table I illustrates the anticipated chamber lamp heat loads for both present and future configurations.

TABLE I

SUN SIMULATOR - HEAT & POWER LOADS

CHAMBER B

	No. of Modules	Chamber Heat Load (KW)	Power to Lamps (KW)	External Cooling (KW)
PRESENT CONFIGURATION	1	5.25	35	29.75
EXPANDED CONFIGURATION				
I 13' x 14' Test Area				
Top Sun	4	21	140	119
Side Sun	9 (5 lamp)	33	225	192
II 13' x 14' Test Area				
Top Sun	4	21	140	119
Side Sun	15 (5 lamp)	56	375	319

SECTION III - E
VEHICLE HANDLING

1.0 Vehicle Mount and Handling

1.1 The vehicle is supported at the base by the framework of the lunar plane. This plane does not rotate as in Chamber A but is constructed so that a scaled down version of the rotary mount in Chamber A can be installed in the future. The surface of the mount is black cryogenically cooled aluminum plate with strip heaters provided below the plating to obtain the lunar plane temperatures.

1.2 Test articles are installed in the chamber by lowering from above after the vessel head has been removed by the overhead crane.

1.3 Fig. III-7 illustrates the fixed base arrangement while Fig. III-8 illustrates the future conversion to a rotary mount.

SECTION III-F
REPRESSURIZATION

1.0 General - The repressurization system for Chamber B is indentical in all respects, except size, to that of Chamber A, described in Section II-F. The size of the system is proportional to the relative volume of the chamber.

SECTION IV
CHAMBER D

1.0 Introduction - It should be recalled that Chamber D is not in the Scope of the integrated Space Chamber Facility, although the general arrangement shows this facility as an extension of the Chamber Building.

2.0 Vacuum Chamber

2.1 General - The vertical, cylindrical chamber assembly furnishes a free working space of 6 ft diameter and 6 ft in length. It is capable of operation at ultra-high vacuum levels of 1×10^{-10} torr or less, using the pumping means detailed elsewhere. A double wall construction is provided. The general arrangement of the chamber and accessories is illustrated on Fig. IV-2.

2.2 Vessel - The working space is surrounded by a liquid helium cooled shroud, approximately 7 ft diamter by 8 ft high, which in turn is enveloped by the guard vacuum barrier, approximately 9 ft diameter by 10 ft high. The main chamber, which will enclose the guard vacuum chamber, is approximately 11 ft diamter by 14 ft high.

The liquid helium cooled shroud is provided with chevron type optically dense gas paths in the portion of the shroud which faces the vacuum pumping ports. The liquid nitrogen shroud is fabricated of Series 300 stainless steel, capable of withstanding thermal cycling between $5^{o}K$ and $475^{o}K$.

The guard vacuum barrier surrounding the liquid helium shroud is fabricated from Series 300 stainless steel, capable of withstanding thermal cycling between $77^{o}K$ and $475^{o}K$. The walls of the guard vacuum enclosure are designed to withstand full atmospheric external pressure. This requirement is dictated first, to protect the equipment in the event of failure of the guard vacuum system and second, to permit proper leak detection of this portion of the chamber. Two 48 inchdiameter vacuum manifolds are welded into the guard vacuum chamber. Welded construction will be used throughout the manifolding up to the diffusion pump connection. The complete guard vacuum enclosure, including the vacuum pump manifolding, is provided with channeling for directing liquid nitrogen and gaseous nitrogen flow for proper temperature conditions over the entire guard barrier surface.

The outer chamber is fabricated of 304 stainless steel and provided with two ports which are concentric with the 48 inch ports of the nitrogen cooled barrier. They form the outside wall of the double walled pumping ports. The design of the outer port enclosure makes allowance for free relative movement of the inner pumping port, due to thermal cycling. The support system for each of the pumping port assemblies provides an arrangement for proper guidance of movement due to thermal cycling.

The chamber is provided with a removable top cover for loading the test specimen. The inner liquid helium cooled shroud, the guard vacuum barrier and the outside chamber each will have separate removable covers, which will be connected to each other in such a manner, that hoisting of the outer cover will remove the three covers and load (simultaneously). A load of up to 2000 pounds may be supported from the guard vacuum barrier cover by hangers. These will penetrate the liquid helium cooled shroud cover.

The interconnecting suspension system between the outer cover and guard vacuum cover as well as between the guard vacuum cover and shroud cover, is a low thermal loss system of sufficient strength to support the cover and specimen load.

The supports for the liquid nitrogen shroud assembly and the guard vacuum barrier are of long path low thermal loss design, with supports for the guard vacuum barrier of sufficient strength to support the shroud, guard vacuum barrier chamber and the 2000 pound specimen load.

The interior surface of the outer chamber, including the pumping port outer walls arepolished to a #4 finish, to reduce to a minimum, the thermal losses to the barrier wall. The outside surface of the guard vacuum barrier will be polished to a #4 finish. The inner surface will be polished to a 32 micro-inch R. M. S. finish for minimizing radiant energy transfer between outer chamber and inner chamber and between the inner chamber and cryopanel.

The fabrication techniques used in the construction of the outer and inner chambers will follow the best vacuum practices, eliminating all pockets and sources of virtual leaks.

Finishing materials used on internal surfaces are carefully selected abrasives and vehicles to avoid trapping of organic materials within or below the polished surfaces.

Penetrations in the main body of the chamber will include:

1. Inlet and outlet lines for the liquid helium shroud.
2. Inlet and outlet lines for the liquid nitrogen cooled inner chamber.
3. An optical viewing port.
4. Two 8 inch diameter blanked-off ports.
5. A port for the addition of a rotary motion feed-through device.

These feed-throughs will penetrate both outer and inner chamber walls and are designed for low thermal loss between the two walls and for an allowance of differential movement of the two walls due to thermal cycling.

Feed-throughs and penetrations located in the top cover include:

1. Liquid helium inlet and outlet lines for the shroud cover.
2. Liquid nitrogen inlet and outlet lines for the guard barrier cover.
3. Solar simulator lenses.
4. Instrumentation port or ports for introducing up to 200 thermocouples into the test area.
5. Two vacuum gauges.

3.0 <u>Pumping System</u> (Figs. IV-2, IV-3 Schematic Diagrams)

3.1 <u>Test Specimen Enclosure System</u>

3.1.1 Performance - The vacuum pumping system with associated cryogenic shroud will be capable of producing pressures within the 6 ft diameter by 6 ft high work space of 1×10^{-10} torr or better in 24 hours or less without a specimen in the chamber. This system will also be capable of maintaining a pressure in the 10^{-6} torr range during backout of the chamber. It will furnish the following pumping capability at higher pressures:

Pressure Level	Gas Load
1×10^{-8} torr	6×10^{-5} torr lit/sec
1×10^{-6} torr	8×10^{-3} torr lit/sec

3.1.2 System Description - The system provided is of the "valveless" type. There will be no valving between the diffusion pumps and the chamber.

Optical baffles and traps are provided between the diffusion pumps and the chamber to insure a minimum of backstreaming and oil migration into the chamber.

Each of the diffusion pumps, connected into the ultra-high vacuum chamber, will be manifolded in series with a separate oil diffusion pump to maintain pressure within the diffusion pump at the lowest possible level during initial heat-up of the main pumps and while operating in the 10^{-10} torr range.

One large mechanical pump is provided for rough pumping of the ultra-high vacuum chamber. This pump will become the common backing pump for the main diffusion pumps, when they are operating in the 10^{-6} to 10^{-3} torr range. "Roughing" of the chamber will be done through the diffusion pumps.

3.1.3 Component Description - The major components of the ultra-high vacuum pump system are:

a. One 400 CFM mechanical vacuum pump for rough pumping the chamber and later backing the diffusion pumps. This mechanical pump is provided with an oil level indicator, thermostatically controlled cooling water supply valve, an oil separator on the pump discharge, safety guards for the V-belt drive and a flexible connector for isolation of the minor pump vibration from the rest of the system.

b. Two 50,000 lit/sec "First Stage" diffusion pumps, operating with a low vapor pressure, high performance pump fluid. The cooling water circuits for the pumps are provided with flow switches to prevent pump operation during conditions of inadequate water flow.

c. Two 4100 lit/sec "Second Stage" diffusion pumps, operating with a low vapor pressure, high performance pump fluid. Waterflow switches are to be provided to prevent pump operation during conditions of insufficient water flow.

d. Two 30 CFM mechanical vacuum pumps, one for backing ea h of the 4100 lit/sec diffusion pumps. Each mechanical pump is provided oil level indicator, safety guards for V-belt drive and flexible connector for isolation of pump vibration from rest of system.

e. Two water cooled damper baffles, located directly above each "First Stage" diffusion pump. These baffles are to be closed during diffusion pump "heat-up" and "end-of-cool down", at which times the upper jet vapor streams are extremely unstable and consequently their backstreaming is relatively high. The closed baffle will effectively condense and collect the backstreaming oil and prevent it from entering the liquid nitrogen traps.

f. Two optically dense, liquid nitrogen cooled traps, one positioned above each of the damper baffles. Each trap is provided with an automatically controlled liquid nitrogen fill device to maintain liquid nitrogen at a proper level.

g. Two optically dense liquid nitrogen traps, positioned at inlet to the 4100 lit/sec "Second Stage" diffusion pumps.

h. One set of pneumatically actuated "failsafe" type vacuum valves.

3.2 Guard Vacuum Enclosure System

3.2.1 Performance - The separate pumping system, provided for pumping the space between the outer and inner chamber will evacuate it to pressures in the 10^{-6} torr range.

3.2.2 Component Description - The major components of the guard vacuum pumping system include:

a. One 400 CFM mechanical pump (similar to Item a. paragraph 3.1.3. above).

b. One 32,000 lit/sec diffusion pump. The cooling water circuits for the pump are provided with flow switches to prevent pump operation under conditions of inadequate water flow.

c. One optically dense, liquid nitrogen cold trap positioned directly above the diffusion pump.

d. One set of pneumatically actuated "failsafe" vacuum valves.

3.3 Utility Requirements

3.3.1 Electrical Services and Cooling Water

		Electrical	Water
a.	**Ultra-High Vacuum System**		
	One - 400 CFM Mechanical Pumps	20 HP	5 GPM
	Two - 50,000 lit/sec Diffusion Pumps	16 KW each	3 GPM
	Two - 30 CFM Mechanical Pumps	1-1/2 HP each	- - -
	Two - 4100 lit/sec Diffusion Pumps	3.9 KW each	0.5 GPM
b.	**Guard Vacuum Pumping System**		
	One - 400 CFM Mechanical Pump	20 HP	5 GPM
	One - 32,000 lit/sec Diffusion Pump	24 KW	4 GPM

3.3.2 Liquid Nitrogen

a.	**Ultra-High Vacuum Pumping System**	
	35 inch Optical baffle cold trap (each)	
	cool and fill	75 liters
	Operational consumption	75 lit/day
	10 inch Optical baffle cold trap (each)	
	cool and fill	3.5 liters
	Operational consumption	1.6 lit/hour
b.	**Guard Vacuum Pumping System**	
	32 inch Optical baffle cold trap	
	cool and fill	75 liters
	Operational consumption	75 lit/day

3.3.3 Compressed Air - 100 psig, clean, oiled for valve actuation, nominal amount.

4.0 Vacuum Instrumentation

4.1 General - The choice of commercially available instrumentationfor the measurement of pressure in the XHV region is relatively limited. Although specially manufactured gauges could be provided, based on various designs reported in literature, their supply and

calibration may present problems. A selection from established commercial sources has therefore been made. These gauges are readily available in their standard form or capable of adaptation with relatively minor modifications at predictable expenditure of time and funds.

4.2 Description

a. Ultra High Vacuum - Two inverted magnetron cold cathode "Redhead" gauges are provided. The sensing elements will require adaptation for their preferred locations in the test space. They will be of a "nude" design, that is, less the conventional and tabulated glass envelope.

The units are modified from basic commerical equipment such as NRC Model 552, or equal.

Each tube will be furnished with an ultra high vacuum gauge control unit, NRC Model 752, or equal.

The operating range of the gauge is 10^{-4} torr to less than 10^{-12} torr, with selective indication in 9 linear scales from 10^{-4} torr to 10^{-12} torr (full scale).

b. Guard Vacuum - Pressure measurement is provided by two hot wire ionization gauges capable of measuring pressures in the range of 1 torr to below 10^{-7} torr. Gauges of the inverted Bayard-Alpert Type or Nottingham Type are furnished, such as NRC Model 551 or equal with decade switched control units, NRC Model 751 or equal affording readings in the desired range on switched linear decade scales.

c. Fore Vacuum and Mechanical Pump Performance Pressure measurement facilities are provided at critical points for the range of 2 torr to 10^{-3} torr. A multiplicity of thermocouple gauges NRC Model 521 or equal, with appropriate read out and control units are furnished. The control units are NRC Model 721 or equal.

d. Leak Detection - A helium sensitive mass spectrometer type leak detector is supplied. A commercial unit, with a sensitivity of at least 10^{-10} standard cc of air and a discrimination capability of 1 part of helium in 10^{7}, is selected. Units of this type are manufactured by General Electric Company (Model M-60), Vecco Corporation (MS-9A) and Consolidated Vacuum Corporation.

e. Partial Pressure Analysis - A mass spectrometer type partial pressure analyzer will be supplied. The unit will be the best available at the time of facility construction. Provisionally, a General Electric Company product, based on the designs of T. A. Vanderslice and W. D. Davis, as reported in Trans. AVS 1959, 6, 146, has been selected. This unit is commercially available and can be adapted for the intended service.

It has a partial pressure sensitivity of 10^{-13} torr and a resolving power of 100. It is capable of measuring a lowest total pressure of 2×10^{-10} torr.

5.0 Cryogenic Systems

5.1 General - Chamber D consists of a stainless steel outer shell, a stainless steel inner liquid nitrogen shell and an inner stainless steel shroud of basket construction, which forms the liquid helium heat sink and cryopump. The space between the outer shell and the liquid nitrogen shell is pumped down with diffusion pumps to create a guard vacuum of 10^{-6} torr.

5.2 Thermal Shield - The liquid nitrogen wall constitutes 260 sq ft of panel area. Both sides of this wall are highly polished. The joint between the wall and the head, which forms the shell, is precision ground. The 1/2 inch OD stainless steel tubes which carry the liquid nitrogen, are brazed or welded directly to the outside of the shell within the guard vacuum area.

Liquid nitrogen is fed to the tubes by a one-inch supply line. Discharge is through a one inch line to a common liquid nitrogen return line to the refrigeration system. The feed and discharge lines are insulated with polyurethane foam.

The liquid nitrogen refrigeration load is as follows:

Chamber Conduction Heat Leak	0.3 KW
Chamber Radiation Heat Leak	4.0 KW
Line Loss (Heat Leak)	0.5 KW
Pump Work	0.2 KW
Total - Thermal Load	5.0 KW

5.3 Heat Sink - Cryopumps - The liquid helium panels constitute 350 sq ft of panel area. The sides of the panels facing the nitrogen wall are highly polished. The sides of the panels facing the inside of the chamber will require additional study for surface treatments to obtain maximum emissivity. The wall panels are 90 degree angle V-shaped stainless steel panels arranged to make the wall optically tight. Stainless steel 3/8 inch tubing is attached inside the neck of the vee of each panel to carry the liquid helium. Openings are provided to allow the escape of any gases trapped between the panel and the tubing. The helium panels at the bottom of the shroud will be dished-shaped formed panels.

Liquid helium is fed by a 1/2 inch line to the center of the bottom panels. It flows through the bottom panels, up through the wall panels, and out the top of the shroud through a 3/4 inch return line to the refrigeration system. These lines are vacuum-jacketed and are insulated with super insulation.

The liquid helium refrigeration load is as follows:

Test Article	0.5 KW
Chamber Conduction Heat Leak	0.2 KW
Chamber Radiation Heat Leak	0.2 KW
Solar Simulator	1.7 KW
Line Loss and Miscellaneous Heat Leak	0.4 KW
Total - Thermal Load	3.0 KW

Support of the liquid nitrogen wall and helium shroud will be accomplished by tie bars and rigid supports which will produce a low-loss, long-path support system. The maximum heat leak through the support system will be approximately 0.2 KW.

The specimen and all instrumentation for the specimen is brought in through the top cover assembly.

6.0 Refrigeration Plant

6.1 General - The helium reliquefier is sized to handle a refrigeration load of 2.9 KW which is sufficient to cool the heat sink cryopump surface of the chamber. Twenty-two pounds of gaseous helium are liquified per minute.

A schematic flow diagram for a helium reliquefier is shown on the right side of Fig. V-2.

Because of the difficulty in transferring liquid helium the refrigeration plant is located in close proximity to and to the west of Chamber D. The space required is shown in plan vew on Fig. IV-4.

The power demand required during peak testing is 1400 KW. Approximately 10 GPM of cooling water make-up is required and one GPM of liquid nitrogen is required.

6.2 Plant Description - The plant consists of the following major pieces of equipment:

a. Surge Tank
b. Helium Compressor
c. Heat Exchangers
d. Nitrogen Adsorber
e. Nitrogen Evaporator
f. Expansion Turbine
g. Subcooler
h. Flash Tank

6.2.1 Description of Equipment

Surge Tank - The make-up helium surge tank is a cylindrical, dished head tank which functions to dampen pulsation of the make-up helium feed to the compressor inlet pressure control valve.

Helium Compressor - This compressor is a reciprocating, non-lubricated machine, driven by an electric motor and used to recompress the helium returning from the system. The machine is provided with controls to provide a constant mass flow of helium into the system.

Heat Exchangers - The three system heat exchangers are coiled tube-in-shell exchangers. The process flow is through the coiled tubes while the cooling flow is countercurrent in the shell side.

Nitrogen Adsorber Cylinders - The nitrogen adsorber consists of two vertical cylinders piped in parallel and valved so that one cylinder can be used for adsorption while the other is being reactivated or is on standby. The function of the adsorbers is to purify the helium stream of nitrogen and trace impurities by adsorption on a bed of activated carbon. The cylinders are designed and piped for top-to-bottom flow. Reactivation flow is in the same direction.

The helium stream enters the cylinder through the cylinder top nozzle and passes through a filter-screen assembly which extends into the adsorber cylinder and which is surrounded by activated alumina. The stream then passes through a bed of activated charcoal and through a second filter screen assembly at the base of the cylinder.

Each cylinder is equipped with an adsorbent fill plug at the top and a drain plug at the bottom.

The adsorbers are supplemented by the necessary reactivation equipment including a reactivation heater and chiller.

Nitrogen Evaporator - This evaporator is a coiled tube-in shell vessel with an automatic controller for maintaining a constant level of liquid nitrogen in the shell. Process helium flows through the evaporator tubes where it is cooled by boiling the liquid nitrogen in the shell, the resultant nitrogen vapor being vented from the vessel.

Expansion Turbine - This turbine is used to supply refrigeration by expanding the high-pressure gas from the helium compressor. As the gas expands through the turbine, its temperature is lowered to the design level of the system.

Helium Subcooler - The subcooler is a coiled tube-in-shell vessel in which vapors from the flash tank and external load pass through the shell side to cool the process flow in the tube side.

Flash Tank - This tank receives the process flow after it is flashed through the expansion valve. The liquid phase settles in the bottom of the tank and is directed to the external heat load, while the vapor phase leaves the top of the tank to join the vapor helium returning from the external heat load.

6.2.2 Process Description - The helium compressor feed is vaporized "return" helium and make-up gas helium, as necessary. A pressure control valve maintains the compressor feed pressure constant.

The compressor discharges into the tube side of the first heat exchanger, where it is cooled by the countercurrent flow of return gas helium in the shell side.

The process flow then passes through the nitrogen adsorber where trace impurities are removed and then enters the tube side of the nitrogen evaporator where it is further cooled by boiling liquid nitrogen in the shell side.

The flow passes through the tubes of the second heat exchanger and then is split into two streams. One stream is directed through the tubes of a third exchanger while the other stream is directed to the expansion turbine where both the temperature and pressure are lowered. The turbine discharge is directed into the shell side of the third heat exchanger and joins the vaporized return helium to help cool the process helium flow in the exchanger tube side.

From the third exchanger, process flow passes through the subcooler tube side and then is expanded into the flash tank by an expansion valve.

The expansion of the helium stream results in partial liquefaction. The liquid drops to the bottom of the flash tank from which it is directed to the external heat load. The vapor leaves from the top of the tank and joins the vapor stream returning from the heat load. The combined streams pass back through the shells of the subcooler and exchangers, and are returned to the compressor suction.

Helium losses amount to approximately 780 SCFH.

7.0 Solar Simulation

7.1 Introduction - The solar simulation in the ultra high vacuum system, Chamber D, is provided by an external module which projects downward radiation through a series of vacuum windows and collimating lenses onto the test vehicle (Fig. XVI-11). The external module is identical to a top module of Chambers A and B. The internal optical elements not only collimate the radiation, but also prevent molecular diffusion into the ultra high vacuum portion of the system. Furthermore, the optical elements are cooled to progressively lower temperatures from the room temperature window-lens assembly to the liquid nitrogen cooled intermediate lens and finally the liquid helium cooled cellular pseudo Fresnel lens. This sequential cooling reduces the heat load on the liquid helium cryogenic system and provides a method of obtaining a temperature approaching absolute zero surrounding the test vehicle, even in the directionof the simulated solar radiation.

7.2 External Module - The external solar simulator module consists of a close-packed array of seven 5 KW high pressure Xenon arc lamps and associated condenser optics. The power supplies and controls for the lamps would be located remotely and connected by cables. The intensity of illumination can be controlled by the number of lamps burning and the power provided to each lamp. The module will be water and air cooled, and the lamps can be changed while the

system is in operation. The reflectors surrounding the lamps are designed to minimize the effect of a lamp explosion.

The radiation from the high intensity arcs would be brought to a common focus by the elliptical mirrors surrounding each lamp. This common focus is just above the window-lens assembly.

7.3 Window-Lens Assembly - The window-lens assembly would consist of fused silica lenses designed to project into a parallel beam the radiation imaged on the area of common focus. These lenses would be vacuum sealed, with a guard vacuum between. The lenses would be protected by a fused silica plate from possible damage due to falling fragments or debris occuring if a lamp explodes.

Each lens of the mosaic lens assembly is small compared with the beam size; consequently, the radiation over its surface is essentially uniform. Therefore, each lens of the mosaic has the characteristic of a uniform point source, which is projected by the collimating lenses into a beam of parallel, uniform radiation.

7.4 Intermediate Lens - The intermediate fused silica lens would partially collimate the radiation from a mosaic lens assembly and serves as the window through the liquid nitrogen shroud. The lens would be seated on a gold O-ring and precautions would be taken to prevent virtual leaks. The differential expansion between the fused silica and the mounting flange must be considered in the design.

The lens would cool by radiation to the liquid nitrogen shroud above and the liquid helium shroud below. The initial cooling rate of the lens starting at room temperature is on the order of $6^{\circ}C$ per minute. The temperature of the lens would be on the order of $200^{\circ}K$ at the end of the first hour. Further cooling would be extremely slow. It is desirable to have this lens cool to prevent it from radiating to the liquid helium cooled pseudo Fresnel lens. This lens would not heat when the solar simulator is on.

7.5 Cellular Pseudo Fresnel Lens - The cellular pseudo Fresnel lens collimates the radiation and projects it onto the test area. The shadows due to the cellular structure will fill in within a few inches from the structure since the radiation beam is not highly collimated. Each fused silica segment in the lens will have the proper curvature on its surface required to collimate the radiation at the location of the segment. This lens has many of the characteristics of a Fresnel lens. The segments will be thin and fabricated from extremely pure fused silica to reduce absorption and a commensurate localized heat load.

A single solid fused silica lens could be used, in principal, at this location: however, a single lens 3.5 ft in diameter made of the highest purity fused silica would be extremely expensive. Furthermore, this lens would be several inches thick at the center and have a large thermal mass. Consequently, it would take days for it to cool down to liquid helium temperature. In addition, the thick lens would absorb more and produce more heat than the thin segments in the pseudo Fresnel lens.

Each fused silica segment is located on top of its associated cell on the structure. The cellular structure reflects the radiation incident on the narrow edge facing the intermediate lens. The remainder of the structure is blackened and absorbs incident radiation. Each segment cools by radiation upward to the cold shroud and downward to the cellular structure. The solid angle, as seen from the segment, of the opening of the cellular structure facing the test volume is small; consequently, most of the downward radiation of the segment is absorbed by the cellular structure and is not projected into the test volume. The thermal conduction of the cellular structure will be sufficiently great so that the center of the lens does not heat when the solar simulator is on. Also the cellular structure will cool to operating temperature within an hour after the liquid helium cryogenic system is activated. The cellular structure cools by conduction to its perimeter. which is cooled by liquid helium.

7.6 Performance - The overall efficiency of the system from electrical input to luminous power in the test area is approximately 8%. Between three and four lamps will have to be activated in order to achieve 140 watts/ft^2 in the test area. The uniformity in the 3.5 ft diameter central test area is 10% RMS when measured with a detector of 4 x 4 inch sensitive area. The collimation will be less than 5^o half-cone angle. The radiation will be constant in time to 5% per hour. The spectral distribution would be essentially that of a high pressure Xenon arc lamp.

7.7 Upgrading - The system can be upgraded to a higher intensity by activating additional lamps in the seven lamp module. The spectral distribution can be improved by inserting an interference filter in the radiation beam to reduce the large band in the infrared between 0.8 and 1.0 . Quartz heat lamps could be inserted between the intermediate lens and the pseudo Fresnel lens to bring these lenses back to room temperature quickly for rapid access to the chamber.

8.0 General Arrangement - The general arrangement of the Chamber D facility is illustrated on Fig. IV-1. The facility is located in an extension of the Chamber Building towards the south. This location provides Chamber D with the services of the adjoining Chamber Building including the overhead crane. The Chamber Building also benefits from this arrangement since a space to be used temporarily for the head of Chamber B is provided as illustrated on Fig. IV-1. This head storage must otherwise be provided in the laydown area between Chambers A and B, thereby reducing the clear area for test article storage and checkout by 25%.

Chamber D is located at the ground floor level in the facility. Space is provided around the periphery for access and maintenance. To one side of the chamber is located a small clean room. Upon removal, the top head of Chamber D is placed on top of the clean room and is accessible from the interior of the room. Test articles, after preparation, are suspended from the bottom of the head and placed in the chamber by reinstallation of the head.

A door in the south wall permits truck delivery of test articles to a laydown space served by the overhead crane. Test articles can then be transferred to the clean room or elsewhere as required.

The facility control room is located on the ground floor, as are the roughing and backing pumps serving the chamber. At about 16 ft above the ground floor is a platform or mezzanine which is continuous with the mezzanine in the Chamber Building. This platform provides access to the upper areas of the chamber and provides a location for switchgear and solar simulation power packs.

Should additional area be required for offices or data handling in connection with this chamber, it can be added by expansion to the east.

The liquid helium plant serving the facility is located to the west as indicated on Fig. IV-1. This locates the plant in close proximity to the chamber proper.

The above arrangement permits even further extension of the Chamber Building towards the south to enclose other chambers which may be required in the future to support the mission of the Center.

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SECTION V

REFRIGERATION PLANT

1.0 Nitrogen Reliquefaction Plant

1.1 Plant Size - The nitrogen reliquefaction plant is sized to handle the total heat load of the following:

a. Chamber A when a side sun earth orbit test is being conducted (225 KW).

b. Chamber B when an earth orbit test is being conducted (19 KW).

c. The back-up liquid nitrogen required by the helium system for Chamber A for an earth orbit test. (12 KW).

d. The heat load of Chamber D (5 KW).

e. The back-up liquid nitrogen required by the helium system for Chamber D (21 KW).

The total thermal energy removed from the above mentioned sources is 282 KW.

The anticipated nitrogen refrigeration requirements are shown on Fig. V-1 for a 48-hour test period and for a 14-day test period. The peak loads required (lunar landings) are satisfied by using liquid N_2 from a 100,000 gallon storage tank. Liquid N_2 to maintain the storage tank must be supplied from outside sources.

A Schematic Flow Diagram of the nitrogen reliquefaction plant is shown on the left side of Fig. V-2.

1.2 Plant Layout - The equipment, described below, is installed in an intergrated Refrigeration Building and in insulating structures to the west of the Refrigeration Building. A plot plan of the refrigeration plant and associated service areas is shown on Fig. V-4. The right side of Fig. V-3 can be used as a guide if it is required that separate areas be provided for the liquid nitrogen refrigeration unit.

1.3 Plant Description

1.3.1 General - The nitrogen reliquefier is a closed recirculating nitrogen liquefaction system. The liquefaction system is combined with a closed recirculating subcooled liquid pumping system

which is used to provide refrigeration to an external heat load.

The system includes the following equipment:

a. Reciprocating Nitrogen Compressor.
b. Oil Trap.
c. Oil Adsorber.
d. Heat Exchanger.
e. Expansion Engine .
f. Expansion Turbine.
g. Flash Tank.
h. Storage Tank.
i. Liquid Nitrogen Pumps.

1.3.2 Description of Equipment

Reciprocating Nitrogen - The compressor is a multi-stage machine used to supply high-pressure nitrogen to the system. The compressor is motor driven and oil-lubricated. The discharge pressure is automatically held constant by a pressure control valve which is used as an expansion valve at the flash tank.

Oil Trap - The trap, a vertically-mounted cylinder, is installed between the compressors and the oil adsorber to remove entrained oil mist from the reciprocating compressor discharge stream. The nitrogen stream enters the side of the cylinder and leaves through the top. The oil accumulates in the bottom and is removed through a drain.

Oil Adsorber - Final removal of oil from the nitrogen stream is accomplished in the oil adsorber cylinders which are filled with activated carbon. The flow of gas is from top to bottom. Filters are installed in the bottom and top to contain particles of carbon in the cylinders. The filters can be removed through removable flanges. Only one cylinder is used at a time, the cylinders being piped and valved so that one cylinder can be taken off stream and serviced while the second cylinder is in service.

Heat Exchanger - This is a coiled tube-in-shell type exchanger. High-pressure nitrogen gas flowing through the tubes is cooled by returning low-pressure nitrogen flowing in the opposite direction through the shell of the exchanger.

Expansion Engine - The high-pressure nitrogen is cooled in driving the pistons of this engine. The energy used and the reduction in pressure results in a considerable drop in temperature.

The engine is loaded with a motor generator which is used as a motor to start the engine and as a generator when the high-pressure nitrogen becomes the driving force to the engine.. The motor generator acts as a load on the machine to prevent it from overspeeding. The engine discharges to the expansion turbine.

Expansion Turbine - The nitrogen stream is further cooled in expanding through this turbine. The turbine is started by opening its inlet valve and starting the flow to the wheels and is loaded by a second wheel on the same shaft which draws in air from the atmosphere, compresses it, and discharges it back to the atmosphere.

Flash Tank - This is a vertically mounted cylinder in which the liquid and vapor phases of the nitrogen are separated. Vapor leaves the cylinder through the top, joins the stream returning from the external heat load and is returned to compressor suction via the shell side of the heat exchanger. The liquid accumulates and flows from the bottom of the tank to the liquid nitrogen pumps. A gauge is provided to indicate the liquid level in the tank.

Storage Tank - This tank is a spherical vessel in which liquid nitrogen is stored as back-up for the reliquefaction plant and for peak loads. A gauge is provided to indicate the liquid level in the tank.

Liquid Nitrogen Pumps - Three pumps, each sized for half the peak load of a lunar landing test, are provided for Chambers A and B, and two additional full size pumps are provided for Chamber D.

1.3.3 Process Description - The reciprocating compressor is used to compress gaseous nitrogen to approximately 3000 psig. Oil from the compressors is removed in the oil separator and oil adsorber.

The high-pressure nitrogen gas is directed through the tubes of heat exchanger where it is cooled by low-pressure recycle nitrogen returning to the compressors. At an intermediate point a portion of the high-pressure stream is withdrawn from the tubes of the exchanger and delivered to expanders where it is cooled by expansion.

The low-pressure, cold nitrogen from the expanders combines with the returning vapors from the heat load and flash tank, and enters the shell of the exchanger where it cools the high-pressure gas in the tubes.

High-pressure vapor leaving the cold end of the exchanger is expanded through a pressure control valve into the flash tank. Vapor from the top of the flash tank is combined with the low-pressure nitrogen from the return line and from the expanders, and returns to the compressors through the shell of the exchanger.

Liquid from the bottom of the flash tank is the refrigerant. During peak heat loads additional liquid nitrogen is available as make-up from the liquid nitrogen storage tank.

1.4 Service Requirements - The nitrogen refrigeration plant power demand is approximately 3400 kilowatts. Makeup cooling water of 25 gpm is required. The plant ties into facility sanitary and storm drains, and potable water lines.

1.5 LN_2 Make-Up Requirements - Approximately 4000 SCFH of make-up nitrogen should be supplied when the plant is operating. This make-up normally is supplied as a gas; but during peak loads, as a liquid.

2.0 Helium Refrigeration Plant

2.1 Design Size - Because of the difficulty in storing refrigeration at 20°K, the helium refrigeration plant is sized for an expected peak load of 7.5 KW, which occurs when Chamber A is under a lunar landing test.

2.2 Schematic Flow Diagram - Refer to the center diagram of Fig. V-2 for a schematic flow diagram of a typical dense gas helium refrigerator.

2.3 Plant Layout - The helium plant is installed along with the nitrogen plant in an integrated Refrigeration Building, (See Fig. V-4). The left side of Fig. V-3 shows the plant layout should a separate facility be required.

2.4 Plant Description

2.4.1 General - The helium refrigeration system supplies dense helium gas to the cryopumps in Chamber A and maintains the

temperature at 20°K against a heat collection load of 7.5 kilowatts. The system uses helium gas as the working fluid, and uses liquid nitrogen to maintain the Dewar compartment temperature and to provide auxiliary refrigeration for the helium. A high vacuum system is used to maintain the double-walled space of the Dewar vessel at a vacuum of 1×10^{-6} mm Hg, and a somewhat lesser degree of vacuum in the vacuum-jacketed compartments of the lines that carry the helium to and from the external load.

The helium refrigeration system consists of the following primary pieces of equipment:

a. Helium Compressor
b. Helium-Helium-Nitrogen Exchanger
c. Nitrogen Adsorbers
d. Nitrogen Evaporator
e. Helium Exchanger
f. Expansion Turbine
g. Helium Storage Tank
h. Make-Up Dehydrator
i. Defrost heater
j. Dewar

The helium exchanger and the cold end of the expansion turbine are enclosed in the Dewar vessel for maximum protection against heat leak. The helium-helium-nitrogen exchanger and the nitrogen evaporator are enclosed in an insulated cold box.

A high-vacuum system, consisting of a mechanical roughing pump, an oil diffusion pump and a vacuum gauge, is used to evacuate the annular space of the Dewar vessel and the vacuum jacketed piping to and from the Dewar.

2.4.2 Equipment Description

Helium Compressor - The helium compressor is a horizontal, 3-stage unit, with nonlubricated cylinders and a special pressure-sealed "distance piece" or separator compartment between the running gear and the cylinders. The "distance piece" minimizes the escape of any helium leaking through the packing glands and prevents entry of oil from the oil-lubricated running gear into the helium gas system.

Helium-Helium-Nitrogen Heat Exchanger - This heat exchanger is a tube-in-shell vessel located in the cold box.

Helium from the helium-helium exchanger in the Dewar compartment is the shell-side fluid for the exchanger. Nitrogen vapor from the nitrogen evaporator flows through one tube circuit of the exchanger and compressed helium, at approximately 300 psia, flows through the other tube circuit countercurrent to the nitrogen and shell-side helium flows. Compressed helium leaves the exchanger, passes to the adsorbers and then to the nitrogen evaporator for further cooling. Warm helium from the shell side passes to the helium compressor. Nitrogen vapor leaves the heat exchanger and is either returned to its source or is vented to the atmosphere, thus providing a heat discarding process at an initially low temperature.

Nitrogen Adsorber Cylinders - The nitrogen adsorber consists of two vertical cylinders piped in parallel and valved so that one cylinder can be used for adsorption while the other is being reactivated or is on standby. The function of the adsorbers is to purify the helium stream of nitrogen and trace impurities by adsorption. The cylinders are designed and piped for top-to-bottom flow. Reactivation flow is in the same direction.

The helium stream enters the cylinder through the cylinder top nozzle and passes through a filter-screen assembly which extends into the adsorber cylinder and which is surrounded by activated alumina. The stream then passes through a bed of activated charcoal and a second filter screen assembly at the base of the cylinder.

Each cylinder is equipped with an adsorbent fill plug at the top and a drain plug at the bottom.

The adsorbers are supplemented by the necessary reactivation equipment including a reactivation heater and chiller.

Nitrogen Evaporators - This evaporator is a vertical tube-in-shell heat exchanger with a vapor collection space above the tube bundle. A liquid-level control system maintains the level of liquid nitrogen in the shell side so that the tube bundle and helium outlet manifold are always submerged. The liquid nitrogen boils by absorbing heat from the helium passing through the tube bundle. The temperature of the helium is lowered to approximately -316°F; the nitrogen temperature remains substantially constant. The nitrogen vapor from the evaporator passes to the helium-helium-nitrogen heat exchanger and the helium passes to the helium-helium-heat exchanger in the Dewar compartment.

Helium-Helium Heat Exchanger - This heat exchanger is located in the Dewar compartment. It receives return helium from the external load at a temperature of about 20°K in the shell side and high-pressure helium from the nitrogen evaporator in the tube circuit. The high-pressure helium is cooled and passed to the expansion engine. The return flow helium passes out of the Dewar to the helium-helium-nitrogen exchanger and thence to the compressor suction. A bypass valve diverts a portion of the return helium around this heat exchanger to the defrost heater which reduces the refrigeration of the incoming helium, permits its temperature to rise and imposes an artificial heat load to balance the system when the external heat load diminishes.

Helium Expansion Turbine - This is used to supply refrigeration by expanding the high-pressure gas from the helium compressor. As the gas expands through the turbine its temperature is lowered to the design level of the system.

Helium Storage Tank - This tank is a vertical, cylindrical, welded steel tank with dished heads. Its capacity is 1200 gallons (approximately 160 cubic feet). The capacity at the operating pressure of 300 psig is approximately 3400 STP cubic feet of helium. A single connection serves for both inlet and discharge. The charging manifold leads through the makeup dehydrator and connects to the inlet-outlet nozzle. A pressure gauge and safety relief valve are provided on the manifold near the inlet nozzle. A pressure regulating valve is located between the helium storage tank and the system. The system return line to the tank is provided with a check valve to insure return flow only.

Makeup Dehydrator - The makeup dehydrator is a cylindrical column of pelletized desiccant within an enclosed vessel. It is located on the charging manifold upstream of the helium storage tank. The dehydrator is a safety device to insure that only dry helium enters the storage tank and system. The desiccant bed is retained by a plug of glasswool, backed by a screen, at each end of the chamber. The desiccant is molecular sieve material, a synthetic zeolite adsorbent. The top inlet nozzle has a side connection to the high vacuum system to provide for evacuation of air before being initially put into service or after renewing desiccant. The desiccant charge is renewed after 1000 hours of system operation when the system is shut down for defrost.

Defrost Heater - This heater is a horizontal, extended surface, tube-in-shell heat exchanger. Cooling water, which has been passed through compressor jackets, is supplied to the shell

side of the heat exchanger; cold purge nitrogen, followed by cold helium, passes through the tube side. The tubes are finned to present extensive heat exchange area per unit length. The header ends of the tubes are large radius partial helices to accomodate the expansions and contractions over the 500-degree temperature range through which they may vary when put into and taken out of service. The flow of nitrogen or helium and the water is concurrent, to avoid freezing the water. The jacket water flow is 100 gallons per minute and helium flow is 640 pounds per hour. The jacket water outlet valves of the compressor aftercoolers are throttled to increase the water temperature so that the initial dry-out and defrost is carried out at a temperature of about 150°F.

Dewar Compartment - This compartment is a cylindrical vessel with an evacuated space between its double walls. The outer wall of the Dewar serves as a mandrel upon which is a spirally wrapped coil of tubing carrying liquid nitrogen. A third wall surrounds the tubing-wrapped Dewar. The internal surface of the inner Dewar and the internal surface of the third wall are polished to mirror smoothness to reduce heat emission. The inner compartment of the Dewar encloses the helium-helium-heat exchanger and the cold end of the helium expansion turbine. The space between the two inner walls of the Dewar is maintained at a vacuum of 1×10^{-6} mm Hg with the vacuum pump. The interior space within the Dewar received a continuous small flow of helium from an external source, which atmosphere assures heat equalization throughout the region, prevents cold spots, and prevents entrance of air and moisture.

2.4.3 Description of Process - Helium gas is recirculated through the system by the helium compressor. Gas enters the compressor from the surge tank at approximately 16 psia and is discharged at approximately 300 psia.

The discharge pressure of the compressor is maintained constant by a pressure controller. When the discharge pressure rises above the setpoint, the controller valve opens to bypass some of the flow back to the helium gas storage tank.

The compressed gas enters the cold box at near ambient temperature and passes through the tube side of a heat exchanger where it is cooled by helium gas returning to the compressor from the cryopanel circuit and by nitrogen gas from the nitrogen evaporator. The compressed gas next passes the nitrogen adsorbers and then through the tubes of the nitrogen evaporator where it is further cooled by boiling liquid nitrogen in the evaporator shell. The gas makes a final pass through

the tubes of the exchanger where it is cooled by helium gas returning from the cryopanel circuit and then enters the suction side of the expansion turbine. The gas drives the expansion turbine and is discharged at a pressure of approximately 40 psig. The work done by the gas in driving the expansion turbine reduces the temperature of the gas to the temperature required at the cryopanel. The gas is then directed to the cryopanel to provide the refrigeration requirements at the panel.

The helium gas from the cryopanel is returned to the cold box where it is warmed to approximately ambient temperature by providing refrigeration to the compressed helium gas flowing to the expansion turbine. The warmed helium gas is returned to the helium compressor where it is compressed and again recycled through the system.

The expansion turbine and the helium exchanger are located inside a Dewar which is highly protected against heat leak by a vacuum maintained in the annular space of the Dewar and by a flow of liquid nitrogen through the coiled tubes in the annular space. The inside of the Dewar is kept under a constant purge of helium gas which is tapped from the compressed helium stream flowing to the heat exchanger.

In instances where there is no refrigeration demand at the cryopanel, the system can be left operating without the need to adjust the compressor discharge pressure or the expansion turbine speed. The suction pressure at the expansion turbine will drop when there is no heat load at the cryopanel and this drop in suction pressure will decrease the refrigeration output of the system. However, should the temperature of the expander discharge gas approach 5°K, the defrost heater must be put on stream to provide an artificial heat load to the system. This is necessary to prevent the expansion turbine from making liquid.

2.5 Service Requirements - The power demand is approximately 1000 KW. Makeup cooling water of 7.5 GPM is required.. 1 GPM of liquid nitrogen that is totally vaporized is also required and supplied by the liquid nitrogen plant.

2.6 Make-up Requirements - Helium losses are approximately 580 SCFH.

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SECTION VI
BUILDINGS

1.0 Chamber Building

1.1 Type and Size - This building encloses both Chamber A and Chamber B and is approximately rectangular in plan, 266 feet in overall length, 112 feet maximum in width and 90 feet high as shown in Figures I-2, I-3, I-7 and I-8. The end of the building in which Chamber B is located is 87 feet wide and is served by a bridge crane. The test article assembly and checkout area is located on the ground floor between the chambers.

1.2 Superstructure - The superstructure is structural steel frame covered by a siding of pre-cast concrete panels which have the same integral insulation and exposed agregate finish as used elsewhere at the Center. The roof is steel deck covered with rigid insulation and built-up composition roofing. The 90 by 112 foot area which encloses Chamber A is a diagonally braced structure as shown on Figures VI-1, VI-2 and VI-3. The crane bay which also encloses Chamber B is a rigid-frame structure transversely with diagonal bracing longitudinally as shown in Figure VI-3.

1.3 Foundations - The column loads range between 50 and 250 tons requiring pile supported foundations to avoid unfavorable settlements. The Foundation Plan is shown on Figure VI-4. From soil borings on adjacent sites it is assumed that this site is underlain by approximately 58 feet of medium to very stiff clay below which a 30 ft layer of clayey sand with sandstone seams and lenses occurs. Pile capacities were taken from soils engineering reports prepared for Building 2, the Project Management Building which is approximately 1500 feet to the south-east of the Space Environment Chamber Facility. For the preliminary design, cast-in-place, step-taper concrete piles are used, driven to elevation -45 feet which is approximately 5 feet into the clayey sand layer. For this penetration the compressive capacity is given as 60 tons and the tension capacity is given as about 40 tons. These values are used where loads include maximum wind. For all other conditions of loading, more conservative values are assumed, i.e., 50 tons compression and 25 tons tension.

1.3.1. Chamber Foundation - Chamber A is supported in a reinforced concrete pit which is 88 feet inside diameter and approximately 30 feet deep, all supported by 158 piles as shown on Figure VI-4. Chamber B is supported in a similar pit, 55 feet inside diameter and 17 feet deep, all supported by 33 piles. The piles in the central area of these

foundations are spaced to carry hydrostatic uplift pressure due to a water table at Elevation +18 feet. Both of these pits have membrane water-proofing on the sides and bottom to prevent infiltration of ground water. Drainage sumps and sump pumps are provided for incidental drainage or wash down water.

1.4 Service Crane - A bridge crane is provided over Chamber B and the vehicle check-out area. The crane capacity is 50 tons on the main hook and 10 tons on the auxiliary hook. Crane rails are 75'-6" center-to-center and the crane runway is 176 feet long. The crane is pendant controlled from the ground floor level.

1.5 Vehicle Check-out - The clear area 70 feet long and 75 feet wide at the ground floor level serves as the preparation and final check-out area for vehicles or test articles which are to enter either Chamber A or Chamber B.

1.6 Head Storage - The present study provides a storage platform for the head of Chamber B in the vehicle preparation area between Chambers A and B as shown on Figure I-4. An alternate location for the head storage is shown on Figures I-4 and IV-1 which would be provided in the event that this building is extended for inclusion of Chamber D in the initial construction.

1.7 Equipment Access

1.7.1 Walkways - Access to pumps, valves, piping and electrical equipment around Chamber A is provided by main platforms at 17 feet, 33 feet and 63 feet above the ground floor. Access to Chamber B external equipment is provided by perimeter platforms at the ground floor and at the mezzanine level, 17 feet above the ground floor. Two stair towers near Chamber A and one stairway near Chamber B provide access between levels. Platforms and stairways are also in the penthouse over Chamber A for servicing the top solar simulators and the four 25-ton hoists in that area. Platforms and stairways with the building are usually welded steel grating on structural steel framing.

1.7.2 Elevator - A 6 by 8 foot elevator at the north-east corner of the chamber enclosure serves the ground floor and three main platform levels around Chamber A. The elevator is provided for maintenance for operating personnel for small equipment, and for astronaut transportation to the upper level personnel locks.

1.7.3 Doors - Personnel and service doors are of steel construction. A 30 foot wide by 35 foot high vertical-lift door is provided in the west wall which is large enough to clear the maximum size test articles now contemplated.

1.8 Services

1.8.1 Heating, Ventilating and Air Conditioning - (See Figure VI-5) - The building is air conditioned to approximately thirty feet above the floor. The upper section of the building is sufficiently ventilated to prevent the temperature from rising above the maximum allowable value for the electrical equipment.

The air conditioning of the lower part of the chamber building is accomplished by four separate systems. Each system is complete with packaged air handling units having fans, filters, cooling coils, heating coils, return and outside air dampers and mixing boxes, ductwork, air outlets, controls, and appurtenances. Two systems serve the Chamber A area and two systems serve the Chamber B area.

The systems are of the standard low-velocity single-zone type utilizing face and by-pass dampers for temperature control.

Sufficient outside air is supplied by these units to replenish the air being exhausted through the solar simulator elevator shaft and leakage through doors, cracks, etc. These systems are arranged so that 100% outside air can be supplied to the building in the event of failure of the chilled water systems or cooling coils.

Steam for heating and chilled water for cooling are obtained from the services provided by the Center.

The ventilation of the upper part of the chamber building is accomplished by four separate systems, two serving Chamber A area, and two, the Chamber B area. Each system is complete with packaged air handling units having fans, air filters, ductwork, air outlets, controls, and appurtenances. Four exhaust fans mounted near the roof and across the building from the ventilation units exhaust hot air from the building. Slightly less air is exhausted than is supplied by the ventilation units, providing a positive pressure within the building to preclude infiltration of dust and outside air. All air filters are of the automatic renewable media type using glass fibre filtering media in rolls. All air handling units will be V-belt driven, with an adjustable pulley on the motor.

1.8.2 Instrument and Service Air Systems - (See Figure VI-6)

1.8.2.1 Instrument Air - Two full capacity motor driven air compressors supply the instrument air requirements. Each unit discharges into individual air receivers, from which the air passes through a dryer and to the points of application.

The air compressors are rated at approximately 100 cfm of free air at suction conditions with a discharge pressure of 100 psig. The compressors are of the positive displacement, reciprocating, single stage, non-lubricated, continuous duty, motor driven type with a V-belt drive. Intake filters, silencers and after-coolers with moisture separators and drain traps are provided. The compressors maintain receiver pressure by means of automatic unloading devices.

Two receivers are furnished, each sized to provide maximum demand for a period of ten minutes.

One dual chamber, regenerating air dryer utilizing solid desiccants is provided. The dryer is complete with all valves and controls for automatic operation and is capable of continuous delivery of 100 scfm of oil-free air with a moisture content corresponding to a dew point not exceeding - 50°F at 100 psig. Provision is included for bypassing the air drying equipment in an emergency.

1.8.2.2 Service Air - The equipment under this item is indentical to the equipment described above except lubricated compressors are used and the dryer is eliminated.

1.8.3 Cooling Water Supply System

1.8.3.1 General - This system is capable of delivering about 1300 gpm of 85°F water. As indicated on Figure VI-7, the system supplies water for the diffusion pumps, roughing system cooling loops, the solar and albedo simulator cooling circuits, the compressor cooling jackets, and the manlock requirements. The equipment is located so that sufficient area for expansion of the system to about 3100 gpm, the projected requirement, is available.

1.8.3.2 Cooling Tower - This is a counterflow induced draft unit capable of handling the present cooling load. It is constructed of rot and corrosion resistant materials and is complete with adjustable intake covers, drift eliminators, wind baffles, tower packing, distribution system, stairway, fan deck, fan, fan stack and AGMA fan drive. The complete unit is designed to be readily field erected on a concrete receiving basin.

1.8.3.3 Make-up Control - Provisions are included for adding makeup water to the system. This is controlled by the level in the cooled water storage tank. Makeup water is obtained from the fire main system provided by the Center.

1.8.3.4 Cooling Water Transfer Pumps - These pumps deliver cooling water to the points of application outlined below:

LOCATION	HEAT SOURCE	FLOW REQ'D.	FT H_2O TDH	HP REQ'D.
Chamber A	Solar Simulator	350 gpm	150 ft TDH	25
Spare	Solar Simulator	350 "	150 "	25
Chamber B	Solar Simulator	15 gpm	90 ft TDH	3/4
Chamber D (Future)	" "	15 "	90"	3/4
Spare B& D	" "	15 "	90"	3/4
Chamber A	Diffusion Pumps	250 gpm	100 ft TDH	10
Spare A	" "	250 "	100"	10
Chamber B	" "	225 gpm	70 ft TDH	7 1/2
Spare B	" "	225 "	70"	7 1/2
Roughing System		200 gpm	70 ft TDH	7 1/2
Miscellaneous		200 "	70"	7 1/2
Spare Misc & Roughing		200 "	70"	7 1/2

Total connected HP - Approx. 110
Total running HP - Approx. 60

Either vertical or horizontal centrifugal pumps will be provided. If the horizontal type is selected provision will be made for maintaining flooded suction on all the pumps. An emergency low-level pump shut-off is provided. Required chemicals will be fed manually.

1.8.4 Equipment Cooling Systems

1.8.4.1 Diffusion Pump Cooling Water System - The system for the diffusion pumps and associated valves and transition pieces is as shown on Figures VI-8 and VI-9. During warm ambient conditions all cooling water enters the pumps at approximately 85°F.

This warm inlet water temperature will not prevent all backstreaming from the pump proper, but at the vacuum levels contemplated, the valve and elbow will condense all backstreaming before it enters the chamber.

Piping is arranged to permit future up-grading of the quality of the system by adding at some future time equipment to provide chilled water to the valve and transition piece and possibly to the cold cap.

No provision is made in the system for additional diffusion pumps. If this occurs, additional or larger water pumps and suitable piping can be installed. The additional cooling water required for such future pump additions has been considered in alloting space for future cooling towers.

The two cooling water streams to each pump body are controlled by self-contained temperature control valves to prevent over-cooling as well as over-heating. Flow switches are installed in each stream to assure that all cooling water is flowing any time the pump is running. Most water from these systems is returned under pressure to the cooling tower for re-use.

1.8.4.2 Roughing and Backing Pumps Cooling Water Systems - The main roughing system and each chamber backing system have individual cooling water systems. The equipment cooled is indicated on Figures II-12 and II-22 and generally includes all roughing and backing pumps as well as the interstage exchanges. Each man-lock roughing system has a cooling water system similar in design to the main roughing system. All cooling water from these systems is returned under pressure to the cooling tower.

1.8.4.3 Solar and Albedo Simulator Cooling Systems - The solar and albedo simulators of Chamber A have a cooling water system as shown on Figure VI-10. For Chamber B the one simulator module is cooled by water taken from the diffusion pump system for that chamber. The detailed connections are similar to the those of Chamber A. For each module, temperature control valves and quick-disconnects are provided. All water from these systems is returned under pressure to the cooling tower for re-use.

Both the reflectors and the lamps require air cooling as well as water cooling. The reflectors require a total of 17,500 CFM @ 1 inch H_2O static pressure at the point of application. Atmospheric air is supplied for this purpose by a blower taking suction through an air filter. The lamp cooling system required 800 CFM at 2 psi at the point of application. The air is provided by a positive displacement, Roots type, compressor taking suction through a filter.

1.8.4.4 Miscellaneous Cooling Water System - A suitable system is provided for cooling the air-compressors and other miscellaneous equipment. The general design is comparable to the other cooling water systems.

1.8.5 Electrical Power System

1.8.5.1 General - The power supply to the facility as shown on Fig. VI-11 consists of 12,470 volt underground feeders from the facility substation. The Space Environment Chamber Facility, exclusive of the refrigeration building, is served by two 12,470 volt feeders terminating in a grouped arrangement of metal eclosed fused disconnects rated for 500 MVA interrupting duty. Two additional 12,470 volt feeders are required by the refrigeration building, and the necessary distribution equipment is included with the refrigeration equipment. The combined estimated power demand for the main facility building and the pump building is 3000 kilowatts. The estimated demand for the LN_2 and gaseous He refrigeration building is 4500 kilowatts.

1.8.5.2 Unit Substations - A functional and economical division of the main facility building loads is accomplished by the use of five 12,470 to 480 volt unit substations which are provided with overcurrent protection by the 12,470 volt fused disconnects. The 480 volt windings of the substation transformers are solidly grounded wye connected and are direct connected to 480 volt metal enclosed switchgear. All 480 volt switchgear is "fully rated" for the available short circuit duty. Cascaded type overcurrent protection is not used.

1.8.5.3 Motors and Motor Control - Motors rated one horsepower and larger are 3 phase 440 volt except for some special equipment for which 3 phase 440 bolt motors are unavailable. In general, all motors of 50 horsepower and under are controlled by grouped combination motor starter equipment, and motors of over 50 horsepower are controlled by grouped metal enclosed switchgear.

1.8.5.4 Diffusion Pump Heater Control - The diffusion pump heaters are controlled by grouped combination motor starter equipment.

1.8.5.5 Solar and Albedo Simulator Power Supply - The power units of the solar simulator and albedo simulator are supplied from distribution panelboards located in the vicinity of the power units.

1.8.5.6 Lighting - The minimum levels of illumination for the various areas of the building are:

Control Room	50 ft candles
Office Space	100 ft candles
Main Assembly Area between Vessels A and B	100 ft candles
Access ways and upper levels around vessels	10 ft candles

1.8.5.7 Emergency Power Supply - An emergency 3 phase, 480 volt power supply is provided to equipment essential to personnel safety such as the emergency lighting in the chambers and control room, the auxiliary equipment and normal lighting in the personnel locks, and the main elevator motor.

An emergency 3 phase 120/208 volt supply is provided to the instrumentation, to the data handling equipment and to the repressurization control to the extent that these are essential to personnel safety.

1.8.5.8 Conduit and Cable Tray - In general, underground conduit is used to supply motors and equipment located on the ground floor. Ladder type cable trays are utilized for instrumentation and control connections to the central control room and to all power, control and instrumentation connections above the ground floor.

1.8.6 Telephone System - Telephone service to the facility consists of 40 lines which are served by the site telephone exchange board. Approximately 25 of these lines are required in the office and control room areas, and the others are required in the Chamber Building, Pump Building and Refrigeration Building.

2.0 Facility Adminstration Building

2.1 Description - This building contains the facility administrative offices, lecture and conference rooms, the bio-medical facilities, the facility control room and the test data handling area as shown on Figure I-7.

The office space which includes the administrative offices, test engineers and sub-contractor offices, a lecture and training room, and a conference room is 7500 square feet in area and is located on the ground floor level.

The Bio-Medical area is also on the ground floor level and includes the medical offices, an emergency treatment room, the astronaut service and preparation area, change rooms and suit storage facilities. There are 7500 square feet allocated to this area.

The facility control and data handling room is on the second floor of the building adjacent to the Chamber Building and is 40 ft by 200 ft in plan. The north half of the room includes the facility control, test control, vehicle control, and data handling for Chamber A. The south half of the room includes the corresponding equipment for Chamber B. The computer is centrally located in the control room.

2.2 Superstructure - The superstructure of the office building is a light structural steel frame which is fire proofed in the office and bio-medical areas. Transverse lateral support is gained by connection to the Chamber Building. Longitudinally, a moment frame is provided to avoid all diagonal bracing in office spaces. The steel frame is covered on the exterior with insulated pre-cast panels and window walls as described in Section 2.4. The roof is steel deck with light-weight concrete fill and covered with rigid insulation and built-up roofing.

2.3 Foundations - The column loads are relatively light and are supported by belled caissons which are sized for a 2 tons per sq. ft. maximum bearing value on the firm clay. Since the permanent loading on these footings will be much less than the maximum dead load plus live load, the long time settlement of such footings should be small.

2.4 Architectural Features - Exterior facias are pre-cast concrete panels with exposed aggregate. Administrative and bio-med offices on the ground floor have clear window walls. Soffits and overhangs are stucco finished. Window walls are 3/16 inch crystal glass with aluminum framing. Exterior doors are glass aluminum framed, with recessed closers at main lobby doors and panic hardware at the other personnel exits. Hung ceilings are acoustical tile. Lighting is by flush fluorescent ceiling fixtures. Interior partitions are standard movable units with integrally designed door panel units and glass divider units. Floors are vinyl tile on concrete slab in all areas except toilet rooms which have ceramic tile on floors and walls. The office and bio-med areas are separated from the Chamber Building by a concete block wall from the ground floor to the control room floor. A two-hour fire door is provided in this wall for all traffic to the Chamber Building.

2.5 Heating, Ventilating & Air-Conditioning - This building is completely air conditioned for both summer and winter conditions. Design conditions are 20°F D. B. outside, 75°F D. B inside during winter, and 95°F D. B., 80°F W. B., outside and 75°F D. B., 50% R. H., inside for summer conditions.

Four separate systems are provided: one each for the office areas, the bio-med area, the astronaut area, and the Control Room and data handling area. Each system is complete with packaged air handling units,

fans, air filters, cooling coils, heating coils, return air and outside air dampers and mixing boxes, duct work, diffusers, controls and appurtenances. The systems are of the high velocity, medium pressure, dual-duct multiple-zone type, utilizing valve attenuators for each zone (for zone temperature control) which are connected by flexible ducts to ceiling outlets. Ceiling outlets of the combination lighting-air trough design are provided.

A minimum of 10% outside fresh air is supplied by the systems, unless detailed design conditions should dictate that a greater amount is required for ventilation and exhaust system makeup. The systems are also arranged so that 100% outside air can be supplied to the building in the event of failure of the chilled water system or cooling coil. 125 psig steam, reduced to 30 psig, is used for heating and 39°F chilled water is used for cooling. The steam and chilled water are obtained from services provided by the Center in the utilidor system. Air is exhausted from toilet areas directly to the out-of-doors by a central exhaust system consisting of duct work, exhaust fan, and necessary appurtenances.

The air supplied to the building is in excess of that exhausted so that a slight pressure is maintained within the building precluding infiltration of dust and unfiltered air from the outside. The air filters are of the automatic renewable media type using glass fibre filtering media in rolls. All units will be v-belt driven from an adjustable pulley on the motor.

3.0 Refrigeration Building

3.1 Superstructure - A structural steel frame is used for support of the roof and siding which enclose the refrigeration equipment. The siding is precast insulated concrete panels with exposed aggregate, similar to those used on the other buildings in the Center. The roof is steel deck with rigid insulation and built-up roofing. A 10-ton bridge crane is provided over the compressors for general maintenance use.

3.2 Foundations - The foundations for the building are bell-bottom concrete caissons similar to those under the Administration Building. Foundations for the helium and nitrogen compressors are supported on cast-in-place piles. Lighter equipment is supported on spread footings of sufficient size to transmit very low bearing loads to the clay foundation material. The ground floor is a reinforced concrete slab on slected sand fill and is isolated from the vibrating equipment foundations.

3.3. Cold Boxes and Liquid Nitrogen Storage - A spherical liquid nitrogen storage tank 36 feet in diameter and a cylindrical liquid nitrogen surge tank 23 feet in diameter and 41 feet high are located west of the refrigeration plant as shown on Figure I-1. Both of these tanks are supported by reinforced concrete spread footings. Cold boxes for the liquid nitrogen plant are placed in the same area west of the building and are supported by spread footings on firm clay.

3.4 Future Expansion - The building is planned for future expansion of the liquid nitrogen facilities northward with a continuation of the present crane service. The helium plant will be expanded eastward requiring a second bridge crane for servicing.

4.0 Pump Building - The pump building located adjacent to Chamber A contains the roughing vacuum pumps, the cooling water pumps, service and instrument air compressors and fans for solar simulation ventilation.

4.1 Superstructure - The superstructure is a structural steel frame with precast insulated siding and steel roof deck with rigid insulation and built-up roofing. The structure is tied to the Chamber Building for east-west lateral stability and is X-braced in the roof and the west wall for north-south lateral stability. Rolling doors are provided on the south and west walls for equipment access as shown in Figure I-2.

4.2 Foundations - Foundations for the building columns are bell caissons as used for the Refrigeration and Adminstration Buildings. The large pump foundations are spread footings, sized to impose a low bearing load on the clay supporting stratum. Concrete bases for small cooling water pumps and the like are cast integrally with the floor slab. The floor is a 6 inch reinforced concrete slab on slected sand fill, isolated from the larger pump and compressor foundations.

5.0 Site Features

5.1 Roads - All roads and drives except for the vehicle entrance road are 2-inch hot plant mix bituminous surface on a 12-inch stabilized base course with a sub-base as required.

All roads and drives will carry AASHO Standard H-20 truck loading. All roads serving the Space Environment Chamber Facility enter the area from Second Street which is on the west side of the Facility.

The roads shown on Figure I-1 are as follows:

a. A 30 foot wide road to the large vehicle entrance door on the west side of the Chamber Building. This road is an 8-inch reinforced concrete slab.

b. A 20-foot wide road to the service door on the west wall of the Pump Building.

c. A 20-foot wide road between the Refrigeration Building and the Chamber Building which also provides access to the oxygen bottle racks of the Chamber A emergency repressurization system.

d. A 20-foot wide road between the Refrigeration Plant and the cooling tower which provides access to the service door on the east side of the Refrigeration Building.

e. A 20-foot wide road south of the Chamber Building which leads to the ambulance entrance on the south side of the Facility Administration Building.

5.2 Walks - Walkways in the area are 5-feet wide asphalt on a suitable granular base. Connecting with the perimeter walkway, built integrally with the Administration Building, a walkway runs eastward to the Technical Services and Central Data Buildings and a walkway runs southward to the parking lot.

5.3 Parking - No on site parking is available for the space environmental chamber facility. A parking area with a capacity of 150 cars is available about 400 feet south of the facility on the south side of the road.

5.4 Drainage and Landscaping - Natural ground elevation averages about +20' throughout the facility area. Finished grade along the sides of all Facility Buildings is elevation +21 except at the Adminstration Building. The Adminstration Building is surrounded by a terrace of banked earth at elevation +22.5. This treatment corresponds to the architectural treatment used at other office type buildings at the Center.

At all buildings the finish grade is sloped away from the building face to provide positive drainage toward the catch basins and surface ditches which carry storm water to the Center drainage system shown on the Plot Plan.

Provisions is made for sodding of the adjacent ground areas. No other landscaping provisions are included.

6.0 Future Buildings

6.1 Chamber D Housing - The Chamber Building is planned so that it can be conveniently expanded southward as shown on Figure IV-1 for the future addition of Chamber D and its appurtenant equipment. Chamber D requires a liquid helium plant which can be placed adjacent to the Chamber Building on the west side, providing the shortest possible piping for liquid helium.

6.2 Clean Area - In the future a clean room may be required for final cleaning and test article preparation. This area can be provided on the west side of the Chamber Building, adjacent to the crane bay and south of the main vehicle entrance door.

6.3 Expansion Potential - In addition to the above listed expansion potential, the Refrigeration Plant, the cooling tower and the Administration Building have been planned for future expansion. It has also been contemplated that Chamber C can be added in a further extension of the Chamber Building southward or in a separate building in the Facility area.

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SECTION VII

CONTROL AND INSTRUMENTATION

1.0 Limited Centralized Concept

1.1 Main Board Arrangement - The main centralized facility control room is 40 ft wide by 200 ft long and contains instrumentation for the following specific functions:

a. Control of systems used for producing test environmental conditions.

b. Test data acquisition and processing

c. Test vehicle control

e. Safety shutdown

f. Biomedical surveillance

The facility control board for Chamber A is located at the north end of the control room opposite Chamber A with the board for Chamber B at the south end opposite Chamber B. The general arrangement of the control room is illustrated in Fig. I-7. Control room wireways and tubing trays are installed under the main control room floor and run from front to rear on approximate 20 ft centers. Walk-ways are provided alongside these main distribution trays and access is through doors under the mezzanine.

A main header tray below the mezzanine at the front of the control room is used as a common connection to all distribution trays and serves as the main tray between the control room and the chamber areas. This main wireway tray is also directly connected to patch panels located along the front of the control room, under the windows. Access to the main header tray is from the underside of the mezzanine external to the control room. Additional tubing trays and wireways are located at each end of the control room behind the facility control boards.

The main control room floor is provided with several hatches at the rear of the room for access to the cable area below to facilitate installation and circuit check out of additional cable or rearrangement of existing circuitry beyond the scope of patch panel functions.

1.2 System Instrumentation

1.2.1 Control Board - The facility control board is a standard industrial semi-graphic type board. Panel structure is entirely self supporting.

The panel face is stiffened as necessary to support instruments and other devices attached to the board. The control board is constructed of 4 ft - 0 inches wide panel sections which permit removal of replacement of the plastic sheet facing without affecting adjacent sections.

The panel framework supports the air header, tubing and electrical trays or wireways, pressure switches, relays, signal converters, conduit, electrical terminal bases, etc. The framework is designed for access from the rear to all instruments, relays, switches, etc., without interference from support struts.

1.2.2 Instrument Air Supply - The instrument air supply header located at the bottom of the panel includes two pressure regulators and two filters for reducing air header pressure from 100 psi to 20 psi. Regulators and filters are sized for twice the normal panel air consumption and are piped in parallel to allow the servicing of one air filter and its pressure regulator without disturbing operations of the other set. A header pressure indicator, air reduction station and a low pressure alarm are required.

1.2.3 Instrument Air Tubing - All instrument air tubing is 1/4 inches O. D. plastic tubing with brass (plastic tube to 1/4 inches NPT adapters) for connecting to instruments or headers. Tubing is grouped in an orderly manner and all tubing valves used in tubing circuits are properely supported. Care has been taken to make sure tubing does not interfere with instrument access removal.

1.2.4 Instrument Tubing Termination - All instrument tubing terminates at bulkhead fittings located in the outer flange of the tubing gutter at the outer edge of panel structure. 10 percent spare bulkhead fittings are provided for anchoring spare tubing terminals. All transmitter input lines are provided with a 1/4 inch valve followed by a plugged tee located at the underside of the bulkhead fitting to serve as a future test connection for the receiver. Transmitter inputs feeding more than one device include block valves and plugged tees for each device. The same is true for controller output lines feeding more than one device.

1.2.5 Tubing Identification at Termination Point - All instrument tubing terminations are permanently identified with the instrument identification letters, and number and, in addition; are coded, where applicable follows:

V - Control Valve
T - Transmitter
Rs-Remote Set

1.2.6 Pressure Switches Installed On Transmitter Outputs - Pressure switches provided for alarm functions have a visible set point scale and external set point.

1.2.7 Electrical Control Boards - The control room is ventilated and classified as general purpose.

All wiring is enclosed in rigid conduit or metal raceways. Raceways behind the process control boards are 4 inches square minimum cross section and have hinged or screwed covers.

Minimum wire size is 14 AWG, except thermocouple extension lead wires which are 22 gauge. All wiring is connected to terminal strips using insulated resin cone soldered lugs. Direct soldered connections to the terminal strip are not used. All terminal strips are identified and each wire is tagged at both ends with code marking. 10 percent spare terminals are provided in each terminal box.

Power is brought to the control panel at 120 volts and terminals are provided with personnel protection. Separate circuits are provided for each system as well as a disconnect switch. Disconnect switches are provided with thermal protective heaters and are marked with an identification tag.

1.2.8 Alarm Systems - The non-semigraphic panel annunciator is the back lighted illuminated name plate flush mounted type. Lights are accessable from front of panel. Control relays are located in separate relay cabinets at the lower rear section of the control panel. The system has closed field contacts under normal operating conditions. The proposed operation is as follows:

Normal	-	Light off
Alert	-	Flashing red or amber light, horn on
Acknowledge	-	Steady light, horn off
Test	-	Light on

Alarm lights in the semi-graphic panel are single bulls-eye type. Each alarm function requires two alarm lights, one to indicate normal conditions and the other to indicate abnormal conditions. These alarm lights are vertically mounted and have the following designations:

a.	Green light-	Normal
b.	Red light -	High condition or
	Amber light-	Low condition

The proposed operational sequence is as follows:

a. Normal Condition	-	Green light on
b. High or Low Alarm	-	Red or Amber light-flashing, buzzer on
c. Acknowledge	-	Red or Amber light-steady, buzzer off
d. Test	-	Red or Amber light-steady

1.2.9 Semi-Graphic Panels - The semi-graphic flow drawing or raised symbol semi-graphic will use 16 inch high clear panel space between panel elevations of about 5 ft - 10 inches and 7 ft - 6 inches. Semi graphic displays are furnished for the following control panels:

a. Cryogenic
b. Vacuum (Roughing and backing)

The main facility control board for Chamber A is 60 ft long and consists of the following panel lengths.

Solar Simulator	8 ft
Cryogenic	18 ft
Vacuum (Diffusion, Backing & Roughing)	18 ft
Safety Shutdown	4 ft
Video	8 ft
Position	4 ft

The main facility control board for Chamber B is 30 ft long and consists of the following panel lengths.

Solar Simulator	4 ft
Cryogenic	8 ft
Vacuum (Diffusion, Backing & Roughing)	8 ft
Safety Shutdown	4 ft
Video	6 ft

1.3 Local Boards - The local control boards for Chamber A consist of the following:

Solar Simulator	4 ft
Cryogenic	4 ft
Vacuum (Diffusion, Backing & Roughing)	12 ft
Position	6 ft

The local process control boards for Chamber B consist of the following:

Solar Simulator	4 ft
Cryogenic	4 ft
Vacuum	4 ft

The local process control boards are located near the systems as shown on Fig. I-4. The panel construction is similar to the facility control panels of the main control room. The balance of the panel features are as described for those used in the main control room.

2.0 Vacuum Pumping

2.1 Roughing System

2.1.1 General - The roughing system main control room panel consists of a six foot section and includes instrumentation for the following operational functions.

One indicating vacuum gauge with a three position selector switch for selecting one of the three ionization vacuum gauges measuring chamber pressure in the range of 1000 to .0001 mm Hg.

One vacuum Recorder Controller range 0-200 torr for controlling the 20 inch butterfly valve around first stage blowers. This controller is two mode with hand control sub panel.

One hand control station for remote control of the 36 inch butterfly valve to the first stage blower.

One start-stop station for operating stage one blower.

One start-stop station for operating stage two thru five blowers and pumps.

Seven sets of running lights for all blowers and pumps.

One multi-point temp recorder for monitoring temperatures within the roughing pump system.

2.1.2 Additional Features - A semi-graphic presentation of the roughing pump system is shown on the upper 16 inch portion

of the panel. The graphic contains pump motor running lights actuated from auxiliary contacts in the motor control circuits. A separate alarm annunciator is provided for the roughing pump system within this panel. A master switch is provided for the running lights and annunciator with provision for testing all such lamps.

2.2 Backing Systems

2.2.1 General - The backing system main control room panel consists of a 6 ft section with instrumentation for operating a 2000 CFM mechanical booster system with 200 CFM backing pump.

2.2.2 Additional Features - A semi-graphic presentation of the backing system is shown on the upper 16 inch portion of the panel. The graphic contains pump motor running lights actuated from auxiliary contacts in the motor control circuits. A separate alarm annunciator is provided for the backing system within this panel. A master switch is provided for the running lights and annunciation with provisions for testing all panel lamps. A semi-graphic type display of all chamber diffusion pumps with running lights and annunciator functions is also provided on this panel. The diffusion pump running lights are actuated by limit switches monitoring diffusion pump valve stem position. When the valve is closed the pump is not in operation and when the valve is open the pump is in operation. An alarm function is generated whenever a diffusion pump valve closes.

2.3 Diffusion System

2.3.1 General - The diffusion system main control room panel consists of a 6 ft section and includes instrumentation as follows:

a. Three recording vacuum gauges with selector switches and circuitry for selecting outputs from six ionization gauges within the chamber for measurements over the range of 10^{-3} to 10^{-5} torr. The transmitter is provided with a range change selector switch to cover the range from 10^{-3} to 10^{-10} torr.

b. An annunciator system for monitoring diffusion pump parameters for high coolant water temperatures, high current input to pump heaters and loss of coolant water flow or pressure is also provided as part of this control panel. All diffusion pumps are operated and controlled from the local control panel. Each diffusion pump has its own automatic shutdown protective system which shuts down and isolates the defective pump upon high oil temperature high

coolant water temperature and high current to the diffusion pump heater.

Each diffusion pump foreline section includes a thermocouple type vacuum gauge element for measuring pressures in the range of 1 to 50 microns absolute. The read out is a multi-point indicator located on the local diffusion pump control board for monitoring diffusion pump performance.

2.4 Cryogenic System

2.4.1 General - The cryogenic system main control room panel consists of a 4 ft section and includes instrumentation as follows:

a. Eight vertical scale three mode indicating temperature controllers for controlling helium gas outlet temperatures of chamber cryogenic panels. A typical Piping and Instrument Diagram is shown on Fig. VII-1. One multi-point null balance type temperature indicator for monitoring helium gas inlet and outlet temperatures from each cryogenic zone. Spare inlet and outlet thermocouple leads for eight zones terminate within a patch panel located in the main control room. Two thermocouple leads for the main helium gas inlet and outlet headers are also terminated at the same patch panel.

b. Eight pressure indicators or two pressure indicators with two selector switches are provided to monitor pressure within each zone. One temperature recorder with an eight-point switch is provided for control analysis of the controller input signals. Two pressure recorders for monitoring helium gas supply and return header pressures. Eight trip circuits consisting of hand control switches and position indicators for remote operation of each zone inlet shutoff valve.

c. Two temperature recorders for recording main header inlet and outlet helium gas temperatures.

d. One helium gas flow recorder on supply header, one differential temperature recorder or helium gas supply and return header and one helium BTU recorder installed as shown on Fig. 7-1.

2.4.2. Additional Features - The controllers are arranged in horizontal rows so that their control points are all in line, thus any controller deviating from set point is readily detected. A separate alarm annunciator is provided for monitoring abnormally low zone outlet pressures.

A semi-graphic or a partial semi-graphic is provided on the upper 16 inch portion of the panel which includes helium pump motor running lights actuated from auxiliary contacts in the motor control circuit. The main helium header section is included in graphic form and a typical helium zone (one of eight) with associated instrumentation symbols.

3.0 Solar Simulator and Albedo

3.1 Main Panel - The solar simulator main control room panel is an 8 ft section and provides control and supervision for the side sun, top sun and albedo simulators. Control stations are provided for operating the simulator lamps by groups. The simulators are of a modular construction with each module containing seven lamps. Each lamp has a separate power supply unit which is arranged for remote operation.

The control system provides for group operation from the control room of one lamp of each module of a particular system. For example, all of the number one lamps of the side sun simulator modules may be controlled as a group from one control station on the main control room panel. As there are seven lamps in each module seven control stations are furnished on the control board for the side sun, seven stations for the top sun and seven stations for the albedo.

Profile monitors are provided to supervise lamp voltage and light output of a group of lamps simultaneously. Selector switches are provided for manual selection of the lamp group to be monitored.

A common annunciator to detect any malfunction within the solar simulator system is provided at the main control panel. This signal is initiated from an auxiliary contact on the local panel annunciator.

3.2 Local Solar Simulator Panel (4 feet) - A multi-point scanner logger is used to monitor all solar cells and to alarm on "off normal" condition, high or low. The high and low indiex set-points are adjustable external to the logger. The alarms are common

to all points on the scanner but may be specifically identified from the scanner record, that is each lamp may be identified from the record.

A 31 unit annunciator (window type) is provided for monitoring other abnormal conditions for the seven lamp modules.

Each window acts as the monitor for its specific module and monitors such conditions as high-current, high-air temperature, high-cooling water temperature or lamp outage.

In addition, each lamp has a control panel on its own power unit with ammeter, voltmeter, control switches, local remote selector switch, and temperature monitoring instrumentation.

4.0 Vehicle Mount - The vehicle mount instrumentation system consists of a 4 ft section of panel located within the main control room, identified as a "Position" panel and includes instrumentation as follows:

a. One start-stop station with operating lights and forward and reverse indicating lamps for remote operation of the turntable drive motor.

b. One hand control station for adjusting and control of turntable rotational speed between 1/6 th R. P. M. and 1 2/3 R. P. M.

c. One null-balance type position recorder with 12 inch chart for recording turntable position from 0-360°.

d. One motor current ammeter with an external adjustable set point for monitoring motor current.

e. A separate alarm annunciator is provided for monitoring high and low motor temperatures and abnormally high motor torque.

5.0 Heat Sinks and Lunar Plane

5.1 General - The heat sinks and lunar plane main control room panel consists of a 14 ft section, which is a continuation of the cryogenic panel described in paragraph 2.4, and includes instrumentation as follows:

a. Thirty-two vertical scale three-mode indicating temperature controllers for controlling liquid N_2 outlet temperatures of the chamber heat sink panel, (included are two controllers for the lunar plane). A typical Piping and Instrument Diagram is shown on Fig. VII-1.

b. One multi-point null-balance type temperature indicator for monitoring liquid N_2 from each control zone. Spare inlet and outlet thermocouple leads for thirty-two zones are terminated within a patch panel located in the main control room. Two thermocouple leads for each of the four liquid N_2 main inlet and outlet headers are also terminated at the same patch panel.

c. Thirty-two pressure indicators or eight pressure indicators with eight selector switches are provided in monitor the pressure within each zone.

d. Four temperature recorders are provided, one for each group of eight controllers (with an eight-position selector switch) for control analysis of the controller input signals.

e. Five, two pen-pressure recorder controllers with proportional and reset control mode and hand control sub panel are provided to control the back pressures for each of the five intermediate liquid N_2 return headers. The second pen of this controller is for recording intermediate header supply pressure.

f. Thirty-two trip circuits consisting of hand control switches and position indicators for remote operation of each zone inlet shut-off valve.

g. One twelve-point temperature recorder for recording main header and intermediate header inlet and outlet N_2 temperature.

h. One BTU recorder (watt density) installed on the main liquid N_2 headers consisting of a N_2 flow recorder and one differential temperature recorder installed as shown on Fig. VII-1.

5.2 Heat Sink Additional Features - The controllers are arranged in horizontal rows so that their control points are in line, thus any controller deviating from set-point is readily detected.

A separate alarm annunciator is provided for monitoring abnormally low zone outlet pressures. A semi-graphic or a partial semi-graphic is provided on the upper 16 inch portion of the panel which includes liquid N_2 pump motor running lights actuated from auxiliary contacts in the motor control circuits. The main N_2 header section is included in graphic form and a typical N_2 zone (one of 32) with associated instrumentation symbols.

5.2 Lunar Planes - Four null balance type three-mode temperature controllers are used for temperature control between 300°K and 400°K. Several thermocouple signals are provided for each controller using auto-selector circuitry which controls from the highest temperature measurement. Reliability is achieved because, when a thermocouple opens up the next highest temperature becomes the controller input. The controller output is of the P. A. T. type to a motorized final control element for current control to electric heaters. Four overcurrent relays are provided with external adjustable set points which will initiate an alarm on high current to the heating elements.

A multi-point null balance type temperature recorder is provided for monitoring lunar plane temperatures when operating in the range of 300°K to 400°K.

Four start-stop stations are provided for the four lunar plane heating circuits for remote operation from the main control room.

A separate annunciator is provided for monitoring abnormally high temperatures and high current to the lunar plane heating elements.

6.0 Refrigeration Plant - The main control panel for the refrigeration plant is approximately 25 ft in length and is located within the Refrigeration Building. As already described under the cryogenic and heat sinks facility control and instrumentation, there are various alarms and helium and liquid nitrogen pump motor running lights brought back to the main facility control board for monitoring.

BTU recorders are provided for custody-transfer or accounting purposes on all liquid nitrogen and helium gas streams to the facility. The primary measuring elements are located in the main headers adjacent to each chamber.

The BTU recorder charts are collected and integrated by planimetering.

7.0 Facility Protective System

7.1 General - The facility protective system main control room panel consists of a 4 ft section and includes instrumentation as follows:

a. Electrical circuitry including the interlock, trip, alarm and control functions for the emergency re-pressurization system.

b. One emergency trip push button with mechanical guard for manual activation of the emergency repressurization system.

c. A special annunciator is provided to identify and retain the first "in" signal that initiates the emergency shutdown. A flasher is provided for operating remote warning lights and audio devices during an emergency shutdown.

d. One on-off indicating controller for controlling the chamber pressure at the 5 psia value after emergency re-pressurization occurs.

e. Four valve position indicators for each of the four butterfly control valves used for emergency repressurization.

f. One oxygen pressure indicator for each oxygen system used in the emergency repressurization system.

g. A separate alarm annunciator for monitoring oxygen pressure and instrument air supplied to the emergency repressurization butterfly valves.

7.2 Additional Features - This panel also includes two hand control stations for remote control of normal repressurization butterfly control valve for atmospheric air and a second control valve for nitrogen which is used prior to admission of atmospheric air to reduce the pump-down time for subsequent tests.

8.0 Facility Information to Data Handling - Electrical instrumentation connections between the test chambers and the control room are routed through patch panels located on the control room wall adjacent to the Chamber Building. Input to the data handling equipment, that originates from the chamber instrumentation, may be picked up at the patch panels and routed through the cable-spreading area to the data handling equipment. Conversely, signals originating within the data handling system may be routed through similar patch panels when required for facility control.

9.0 Communications - In addition to the site telephone system, the following communication equipment is provided to meet test operation and setup requirements:

a. Public address system with loudspeakers and microphones to cover operating areas in the Main Facility Building, Pump Building and Refrigeration Building.

b. Intercom sets connecting the control room with the local control boards for the solar simulator, cryogenic, vacuum and position.

c. Sound power telephone connections between the various control boards, patch panels and terminal boxes.

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SECTION VIII
DATA HANDLING

1.0 Data Handling System Requirements - The specific requirements for the data handling system are set forth in Volume II, Section XI.

2.0 System Description

2.1 Block Diagram - Fig. VIII-1 is an equipment interrelation block diagram of the system. For each component there is an indication as to whether or not it is included as part of the basic facility cost package, is leased, or must be purchased on program funds.

2.2 Functional Description - Basically the Data Handling System is composed of two general categories: The Facility Wiring and the Data Handling Equipment. The facility wiring provides complete routing of all test leads from a point at the base of the vehicle to a patch panel in the control room. In the patch panel, wires may be connected to any piece of peripheral equipment to the test director and bio-medical console, to the facility control board, or to the computer. The facility wiring items include the chamber penetrations, the chamber junction box, the patch panels, and the control-room-to-junction-box cables.

2.2.1 Chamber Penetrations - This feature includes all cabling, connector plates and chamber penetrations within the chamber area.

2.2.1.1 Vehicle Instrumentation and Control Cables - Chamber A - There are 2,056 leads (including shields) entering Chamber A which are used as follows:

Quantity	Size	Use
4	#10	Vehicle Power
48	#16	Vehicle Control
100	#22 (single)	Vehicle Monitors
433	#22 (tpr shielded)	Vehicle Test Instrumentation
300	#22 (pairs)	Cooper-Constantan Thermocouple Leads

The above leads are grouped in 37 penetration cables. Power leads (#10, #16) use a standard AN type connectors. Instrumentation leads (#20, #22) use Elco type, 50 pin rectangular connectors.

Within the chamber these cables are extended up the shaft of the rotating mount to a connector plate on the mount platform. These cables are designed to permit plus or minus 180 degree flexing. In order to maintain insulation flexibility it may be necessary to provide heating elements on the cables.

2.2.1.2 Vehicle Instrumentation & Control Cables - Chamber B - There are 2306 leads (including shields) for Chamber B which are used as follows:

Quantity	Size	Use
4	#10	Vehicle Power
48	#16	Vehicle Control
100	#22 (single)	Vehicle Monitoring
250	#22 (tpr shielded)	Vehicle Test Instrumentation
500	#12 (pairs)	Copper Constantan Thermocouple Leads

No shaft cables are provided for this chamber since the vehicle mount does not rotate.

2.2.1.3 Penetration Design - A potted "hat", or sleeve, see Fig. VIII-2 is used for penetrations of the chamber wall. The penetration cables pass through a flanged sleeve in which the wires are fanned approximately 6 inches by use of a pair of spacers. Insulation is stripped from all wires for a distance of 2 inches to 4 inches and a special compund is poured into the sleeve to achieve a good seal. All wires are solid conductor and shield continuity is maintained intact by use of nubs. To assemble the penetration to the chamber the "in-chamber" portion of the penetration cable is inserted in a chamber port and the sleeve flange is then bolted to the port flange to achieve a seal. This permits flexibility, a large number of penetrations for a given port size, an excellent seal, negligible cross-talk, and minimum cost. R F penetrations use hermetic connectors mounted in a connector plate.

2.2.1.4 Umbilical Connections - Penetrations are provided in each air lock and in the chamber walls for pressure suit umbilicals. The harness associated with these penetrations and supplied by others is mated to the chamber junction box. A total of 19 penetrations is provided for Chamber A and 11 for Chamber B as described in Section IX - 7.0.

2.2.1.5 Chamber Sensors - Six cables and associated penetrations are provided to permit mating of special facility sensors (pressure, solar intensity, cryo temperatures, table positions, table control, etc.).

2.2.2 Chamber Junction Box - The chamber junction box provides a distribution and junction point for chamber penetration cabling and is also a point at which the chamber cables may be removed and replaced by test cables on the vehicle to permit pre-and post-environmental performance tests. The junction box also provides a certain amount of signal conditioning.

2.2.2.1 Junction - The junction box provides mating connectors and terminal board points for all wires coming from the control room and chamber penetrations.

2.2.2.2 Reference Junction - The junction box contains 5 thermocouple reference panels. These panels provide capability for accepting thermocouple leads of chromel, alumel, iron, constantan, or copper. The panels permit temperature data transmission to the control room via copper wires, resulting in fewer cables, more flexibility and less cost. The reference junctions provide a closely-controlled cold reference. They are energized and controlled remotely from either the computer or from the data handling panel on the test director's console. They are also capable of local energization.

Each panel is capable of handling 100 thermocouples. Three of the five panels are used for vehicle instrumentation; one is used for facility instrumentation; and one initially is a spare.

2.2.2.3 Low Level Difference Amplifiers - Universal, stable DC amplifiers are provided to amplify and condition low level signals. Typical signals requiring amplification are ECG, EEG, or vehicle test signals. Amplifiers are mounted on logic cards and a nest for approximately 30 cards is provided. Power supplies are provided and are capable of local manual or remote switching. Power supply indications are provided remotely to the test conductor console and to the computer.

2.2.2.4 Sensor Power Supplies - Power (5.0 volts DC) is provided from a solid state, remotely programmable power supply for high level sensor energization. Programming is accomplished by the computer. Remote indications and "off-on" controls are provided at the test director console.

2.2.2.5 Umbilical Distribution - Relay switching circuits are provided for continuity monitoring, baro switch monitoring, suit sensor energization, and for information to the bio-medical monitoring console and computer remote indications as to which pressure suits are connected to which umbilical penetrations.

2.2.2.6 Voice Link Amplifiers - Amplifiers and distribution circuitry are provided for the voice links in the pressure suits and for the test conductor and bio-medical monitoring console.

2.2.2.7 Vehicle Ground Power - In order to prevent line loss of the vehicle ground power, it may be necessary to locate a vehicle prime power supply adjacent to or in the junction box. Terminal boards and connectors are provided to permit this interconnection.

2.2.2.8 Junction Box-Control Room Cables - Approximately 2,535 wires (including shields) are routed to the control room. Fifty cables are used. Signal leads utilize number 22 twisted pair shielded sets. Signal cables are terminated on fifty pin connectors and permit 15 twisted pair shielded sets per cable. Shields are maintained individually. Power and control leads utilize special connectors and are terminated in standard AN type connectors. Color coded cables are used to reduce installation and maintenance cost.

2.2.3 Patching Panel - The patching panel is the heart of the test facility wiring. It is the unit which permits complete flexibility. Each wire from the chamber, computer, test director and bio-medical monitoring console, and the facility is routed to a patch panel point. The patch panel is designed to permit patching of any signal to any monitoring or recording station. Thus, it is possible to change the test configuration by inserting a new pre-patched programming board for major changes or by changing a jumper wire for a minor change.

The patching panel is located on the mezzanine at the front of the control room below the observation windows. Openings are provided on each side for access from the mezzanine or control room. It is designed so that the patch panels are accessible to the interior of the control room. The opening on the mezzanine permits cable connection and wiring repair. Cables are routed from the cable trays, located beneath the mezzanine, up through the bottom of the panel.

Four types of patch panels are provided: signal panels, digital panels, power panels, and RF connectors.

2.2.3.1 Signal Panels - Signal panels utilize 1200-point patch panels, divided into three sections. Each of nine connectors from the chamber carry 25 sets of twisted pair shielded leads to a block of 400 points on the panel. There are also nine connectors from the computer scanner-distributor carrying the same number of leads and also occupying 400 points. An additional nine connectors, each carrying 400 points, is available for peripheral equipment (test conductor, vehicle, etc.). If it is necessary to patch a given chamber signal to the computer scanner-distributor, it can be accomplished using a twisted pair shielded jumper. If the chamber signal is utilized by both the computer and some item of peripheral equipment a twisted pair shielded Y jumper is used.

Computer analog output signals for peripheral equipment control is patched directly on the board.

2.2.3.2 Digital Control - These patch panels are primarily utilized for the transmission of digital signals from the computer digital input/output section to the peripheral equipment within the control room. A limited number of digital outputs is provided to the chamber. These patch panels utilize 50 pin connectors.

2.2.3.3 Power Panels - These patch panels are larger in size, utilize fewer pins and are capable of carrying heavy currents. Connections made to these panels are more permanent in nature in order to prevent damage caused by loose patch cables or patching errors. Space is also provided for shunts for current measurements and for circuit breakers, if necessary. These patch panels feed AN type connectors.

2.2.3.4 RF Patching - Coaxial terminal blocks are provided for routing RF signals. Space is provided for directional couplers or detectors. These terminal blocks feed BNC type connectors.

2.2.4 Test Director and Bio-medical Monitoring Console - In order to facilitate test coordination and centralization, and to realize an equipment cost saving these two functions are combined into a single console. Physically, the console is a desk type approximately 20 ft in length. It provides a limited number of terminal boards, since patching flexibility already is provided in the patching panel. An analog display board, TV monitors, and a magnetic tape recorder are also provided as peripheral equipment for the console.

2.2.4.1 Console Control Panel - On-off controls and indications and circuit breakers are provided for the console power supplies.

On-off controls are provided for the voice link equipment and for the analog display unit.

2.2.4.2 Data Handling Panel - On-off controls and indications are provided for the sensor power supply in the chamber junction box and the thermocouple reference junctions. The data handling program start-stop request switches fo 'he computer are located on this panel. A selector switch and display for data point readout requests from the computer are provided.

2.2.4.3 Facility Status - Summation lights for go-no-go facility status indications are provided. These are energized under computer control. Selections and displays for the chamber vacuum, solar intensity & table position are provided. Control switching for changing table position or for permitting computer control of the table position is provided.

2.2.4.4 Vehicle Status - Summation ligh's and a display unit are provided for indicating vehicle key events. The lights have removable screens so that nomenclature changes may be made when vehicle configurations change. These lights and displays are energized under computer control.

2.2.4.5 Prime Subject Monitor Panels - Each man in the chamber or locks has his bio-medical data displayed on an individual panel. Each panel has a selector switch and digital display for blood pressure (systolic), temperature, suit pressure, and oxygen flow data. A small oscilloscope is provided for ECG monitoring. A small strip chart panel-mounted recorder is calibrated to display the rate and depth of respiration.

Indicators are provided for monitoring of suit baro switch closures. There is also an indicator which displays the number of the umbilical penetration to which the astronauts pressure suit is connected. Alarm indication lights are provided and are under computer control.

2.2.4.6 Other Personnel Monitor Panel - A single panel is provided to monitor the activity of all personnel in the chamber. This panel provides fewer readings then the prime subject panels and includes a single scope for ECG monitoring and a selectable display for any one suit pressure, oxygen demand, or temperature reading. These parameters are also continually recorded and displayed on the analog display board.

Alarm lights and indicators indicate which suits are connected into which umbilical connection point and provide monitors for alarm indications for the suit baro switch.

2.2.4.7 Cabin Environment - A selector switch and digital display is provided for the cabin total pressure, oxygen partial pressure, carbon dioxide partial pressure, oxygen supply pressure, humidity and temperature. Indicator lights are provided for go/no-go indications of cabin status and are under computer control. The cabin environmental parameters are also recorded and displayed on the analog display board.

2.2.4.8 Magnetic Tape Recorder Control - Controls and indications are provided for remote operation of the magnetic tape recorder. These include fast forward, fast reverse operation, playback, tape search, tape sense, etc. The recorder itself is a 28 channel direct or FM record/playback machine. It also includes a track for voice annotations. Tape speed compensation is provided. Tape speeds are 7-1/2, 15, 18, and 60 inches per second. IRIG standards for wow and flutter and tape skew are met.

The machine frequency response is $\pm$ 3 db from 100 cps to 250 KC for direct recording and 0-20 KC for FMC recording. Such a machine can be obtained on a lease basis.

2.2.4.9 Closed Circuit TV Monitoring - Four monitor screens are provided. Three are associated with the prime subject monitoring panels and the fourth amy be used by the test director as required.

2.2.4.10 Analog Display Board - The analog display board is a large, wall-mounted back-lit display unit. It permits analog record displays of up to 200 frames of DC data. Four points per frame are possible. It is capable of recording at a rate of one point per second.

The horizontal scale is calibrated in hours and has a maximum capacity of six hours; the vertical scale is calibrated for the particular parameter being displayed. Each frame also has the capability of displaying a flashing alarm signal in the event that an out-of-limits condition occurs.

If possible, the display unit will be designed so that the alarm is set by the computer.

Points to be recorded may include:

Vehicle

- 1 Ground Power Voltage
- 1 Ground Power Current
- 3 Secondary Power Voltage
- 3 Secondary Power Current
- 10 Key Vehicle Electrical Parameters
- 10 Key Vehicle Temperatures
- 20 Key Vehicle Instrumentation Sensors

Facility

- 4 Vacuum
- 10 Solar Intensity
- 1 Table Position
- 20 Cryo Temperatures

Bio Medical

- 15 Prime Subject Sensors
- 10 Cabin Environment
- 18 Pressure Suit Sensors

2.2.5 Process Computer - A large digital process computer should be leased as the basic data handling and test control device. A design study is necessary to determine computer hardware requirements; but, based on preliminary study, tentative specifications for the equipment and description of use and programming requirements can be stated.

2.2.5.1 Basic Computer

2.2.5.1.1 Analog Input Output Section - A scanner-distributor capable of accepting 1500 double-ended or 3000 single ended points should be provided The scanning rate required is 20 points per second. Full range settings of the A/D convertor should range from 10 millivolts to 250 volts. Analog output signals should include ground, 6, 12, 18, and 28 volts DC for various time durations for analog control of peripheral equipment.

2.2.5.1.2 Digital Input-Output Section - There should be 960 digital input points. These points would utilize contact closures and be scanned in groups of 16 at the rate of 200 microseconds per group.

There should be 840 digital output points. These would also take the form of contact closures and should be provided in groups of 12. It requires approximately 50 milliseconds to change the bit configuration of a 12 bit group.

2.2.5.1.3 Central Processor - The central processor should employ a 20 bit word length and have an access time of 20 microseconds for the working memory. The memory provided should be an 8,000 word core for working memory and 57,000 word drum for bulk storage. A digital clock and elapsed time counters should be provided to facilitate real-time programming. Automatic priority interrupts should be available. A floor mounted maintenance and programming console should be provided. The computer should be capable of simultaneous input/output and computational operations.

2.2.5.1.4 Peripheral Equipment - A dual magnetic tape handler (15 KC) and associated tape controller should be provided. Three alphanumeric typewriters should be provided. One should be located at the maintenance and programming console and one should be located at the test director console in both Chamber A and B control room areas.

2.2.5.2 Computer Functions - The computer is provided primarily to handle data for the two chambers. However, it should have sufficient capacity to perform several other required functions discussed below.

2.2.5.2.1 Data Handling-Static Test - As stated in the requirement section there are approximately 1,000 points to be scanned per chamber. These points are divided into five levels of sampling rates depending on importance. The lowest sampling rate would include evaluation data which does not affect safety. These data would be sampled, compared to limits, checked for sensor defects, and formatted for magnetic tape output. It would be correlated with telemetry or facility data and outputted on magnetic tape. Out-of-limits conditions would be typed on the typewriter.

As data points become more important, sampling rates are increased. For the more important points the computer would again check limits, compute new limits from other data or criteria, check for the presence of dangerous trends, correlate data from different sources and supply data on magnetic tape. If alarm conditions exist, the computer would initate corrective action routines. If data trends indicate possible trouble approaching, the program would move the data point involved into a higher level of sampling importance.

For example, a temperature sensor mounted on a critical electronic component may be tested to see if it exceeds a maximum value then may be correlated with data from telemetry, the solar intensity measuring sensors, and the rotating platform position indicator, and recorded on magnetic tape. If a dangerous trend is present, an alarm type-out can be initiated. If the computer senses that the trend would exceed the maximum temperature limit or is in excess of the maximum temperature limit, it can initate a correlative action routine which might consist of tuning the electronic component or requesting that the solar simulator be extinguished.

The most critical data (viability or vehicle safety data) would be sampled at five second intervals and corrective action initiated if necessary. Data displays would be provided at several points (see description of bio-medical and test director console) and would be actuated as part of the program or in response to a request signal from the data display point. Upon receiving such a request the computer would interrupt its normal program (unless a critical function is being performed), make a new measurement on the point in question, and scale and display the current data at the display point.

2.2.5.2.2. Data Handling-Dynamic Tests - The dynamic tests would be short tests of vehicle subsystems performances and would be run relatively infrequently (e.g. every six hours). The computer would program the test sequence and measure the response of the subsystem. Data would be computed and typed out for immediate evaluation. For example, if it is necessary to transmit to the vehicle a timed hot gas orbit correction thrust command, the computer would initiate the transmission of the command via the command ground station, measure the vehicle response time, thrust duration time, polarity, telemetry monitor outputs, etc., for proper subsystem response.

2.2.5.2.3 Emergency - Computer attention to emergency conditions would be accomplished through program interrupts. Two primary functions included in this category are emergency chamber repressurization and vehicle emergency shutdown. For example, if a pressure suit is damaged and subsequently depressurized a baro switch in the pressure suit would close and interrupt the computer. The computer would examine a number of criteria, including a pressure transducer in the pressure suit, the chamber pressure transducers, the suit oxygen flow transducer, possible telemetry monitors, and other viability sensors to determine if a serious rupture of the pressure suit has occurred. If such damage has occurred, the computer would initiate automatic chamber repressurization. This computational process decision would require approximately 250 milliseconds. If insufficient criteria were present to warrant automatic repressurization, the computer would light an alarm indicator on the bio-medical console warning the operator that a human decision should be made.

2.2.5.2.4 Control Functions - The computer would initiate dynamic performance tests. It would also initiate facility operation (solar simulator and rotating table) by output indications to the facility control operator (it is possible that these functions later may be brought under direct control of the computer since all necessary electrical circuitry is already incorporated in the design). The computer may also be utilized to program start-stop of analog data recorders. Push buttons on the test director console would be used to initiate stored, complex test sequences, such as simulating problems to the astronaut crew, measuring and evaluating crew response and providing feedback based on the responses. Changes to these test sequences can be accomplished merely by changing the stored program and changing the nomenclature on the push button. Circuity changes would not be required.

2.2.5.3 Programming - Sufficient memory capacity would be provided to permit executive control of routine programming. Each chamber would have its own individual executive control routine, which may be selected by a master executive routine. There would be a number of common subroutines such as an analog measurement, BCD conversion, and typing, which may be shared. These subroutines would be located in memory locations available to either chamber program and would be protected by disconnecting memory write switches. Elapsed time counters, the digital clock and automatic priority interrupts would simplify the real-time programming problems.

The computer should have its own symbol language assembler program and an assembler program for use with an IBM 7090 should also be provided.

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SECTION IX
MAN - RATING

1.0 Introduction - The conceptual design is based upon providing a satisfactory and economically practical solution to problems of ingress, egress, surveillance, control, and recovery of man in a simulated space environment. Man-rating essentially includes design considerations relating to the safety and support of activities of personnel in the chamber under test conditions.

2.0 Man Locks - Locks provided on Chambers A and B are as follows: (Figs. II-4 and II-5)

Chamber A - One double or parallel lock is at the lunar plane elevation. This lock has two compartments each with a floor area of 9 ft by 12-1/2 ft, five 4 ft by 7 ft doors and nine observation windows. One single lock is at the first catwalk level 29 ft above the lunar plane. The floor area is 9 ft by 10 ft. Two 4 ft by 7 ft doors and four observation windows are provided. Provisions are made for future installations of a single lock at the upper platform level.

Chamber B - One double lock (similar to that in Chamber A) at the lunar plane elevation is provided.

All locks are provided with TV camera coverage, lighting and umbilical and electrical penetrations.

3.0 Internal Catwalks - For personnel circulation and access to test vehicles, two catwalks (42 inch walkway) are provided in Chamber A. One catwalk is 29 ft above the lunar plane and the other 59 ft above.

4.0 Environmental Control Systems - Only the space and provisions for the necessary power are included.

5.0 Rescue Procedure - The rescue procedure is based on the use of the "buddy" system. A portable demand oxygen mask/regulator unit, a "garment bag" pressure suit and a stretcher assembly are to be provided by others as required.

6.0 Automatic Repressurization System - The automatic repressurization system is described in Section II-F 3.0. This system uses a 50% nitrogen-50% oxygen mixture made up of 66% air-33% oxygen meeting the following criteria:

a. 50 mmHg (1.0 psia) in 10 seconds - total pressure
b. 85 mmHg (1.6 psia) in 30 seconds - oxygen partial pressure
c. 130 mmHg (2.5 psia) in 45 seconds - oxygen partial pressure
d. Automatic repressurization not to exceed 260 mmHg
e. Maximum pressure rate not to exceed 0.17 psi/sec
f. Manual repressurization from 260 mmHg to ambient not to exceed 5 psi/min with control and "hold" capability provided through the range.

Manual actuating controls are provided at the bio-medical console. Automatic repressurization by the computer is actuated only from signals emanating from critical suit conditions.

The temperature of the gas 3 ft to 10 ft above the lunar plane is not to exceed the following schedule:

Temperature Range (^{o}F)	Elapsed Time from Start of Automatic Repressurization(Minutes)
- 30 to 200	2
15 to 150	5
35 to 100	10

7.0 Umbilical Connections - A total of 19 connectors are provided in Chamber A and 11 in Chamber B. Three are installed in each single man lock, six in each double lock, and five at each access level. Each connector consists of:

a. Two ducts for gas circulation (3.5-5.0 psia), 20 CFM, 1-1/2 inch pipe.
b. One duct for oxygen supply, 1/2 inch pipe.
c. Twelve channels of electrical circuits

8.0 Biomedical Console - At the Biomedical console located in the control room, provision is made for monitoring personnel in the locks and chambers. The console is designed as an integral part of the Test Director console for both Chamber A and B (Refer to Section VIII, Para. 2.2.4).

9.0 Biomedical and Astronaut Preparation Area - The Biomedical and Astronaut preparation area in the Adminstration Building adjacent to the chambers is illustrated on Fig. I-7. Provision is made for medical personnel, emergency treatment and storage of supplies. Also provided are areas for astronaut dressing. taping, suiting, briefing, and denitrogenation.

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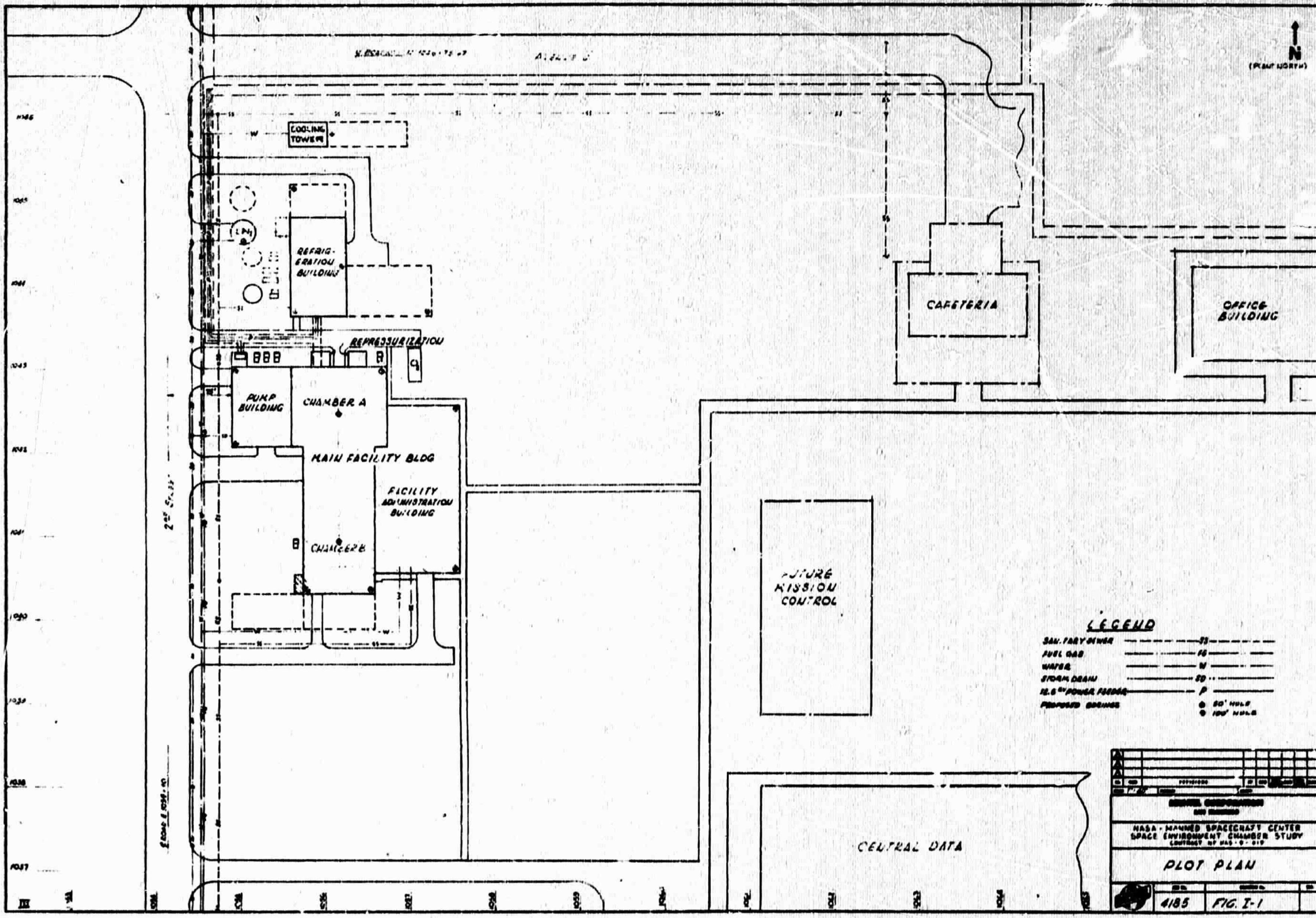
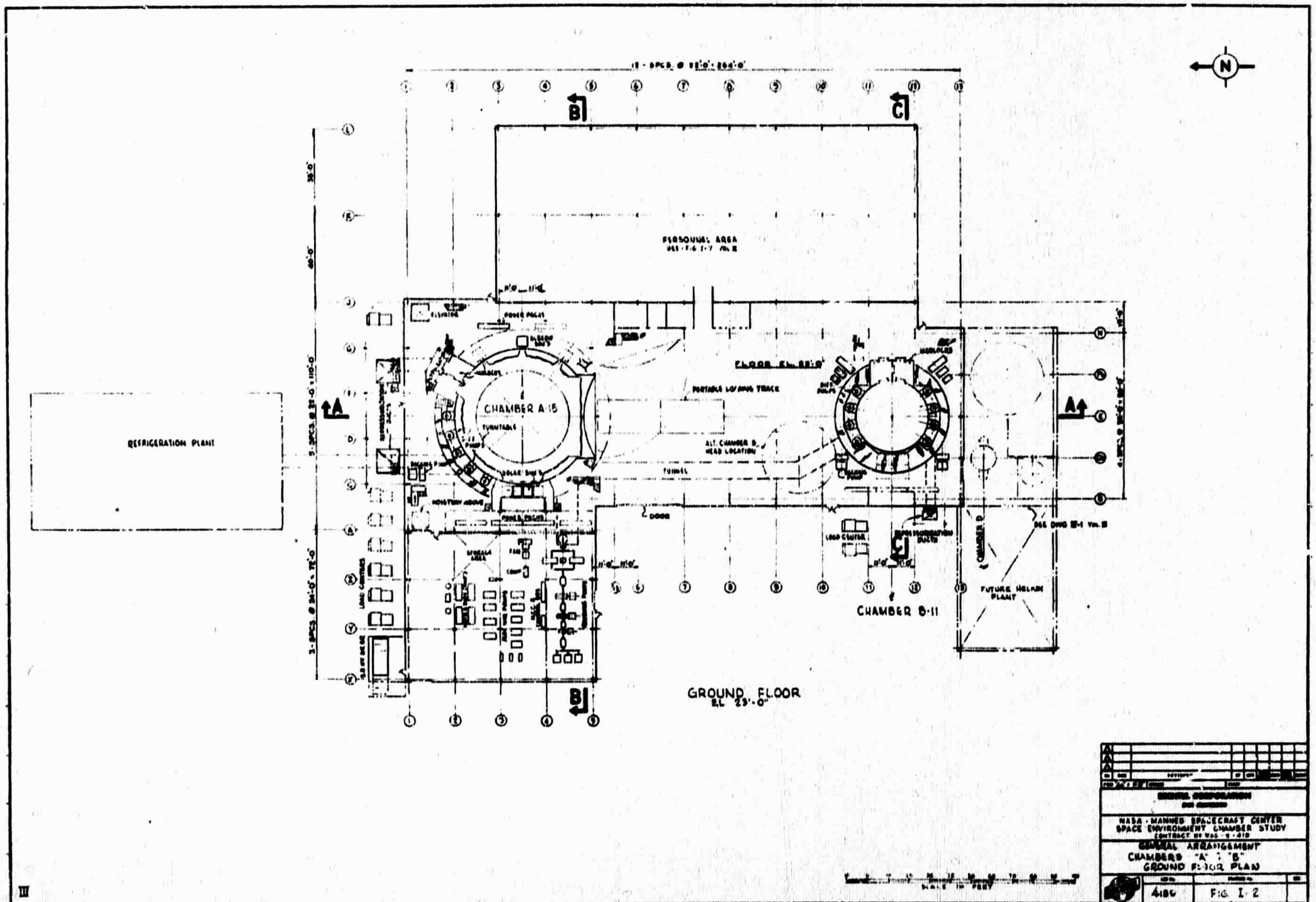
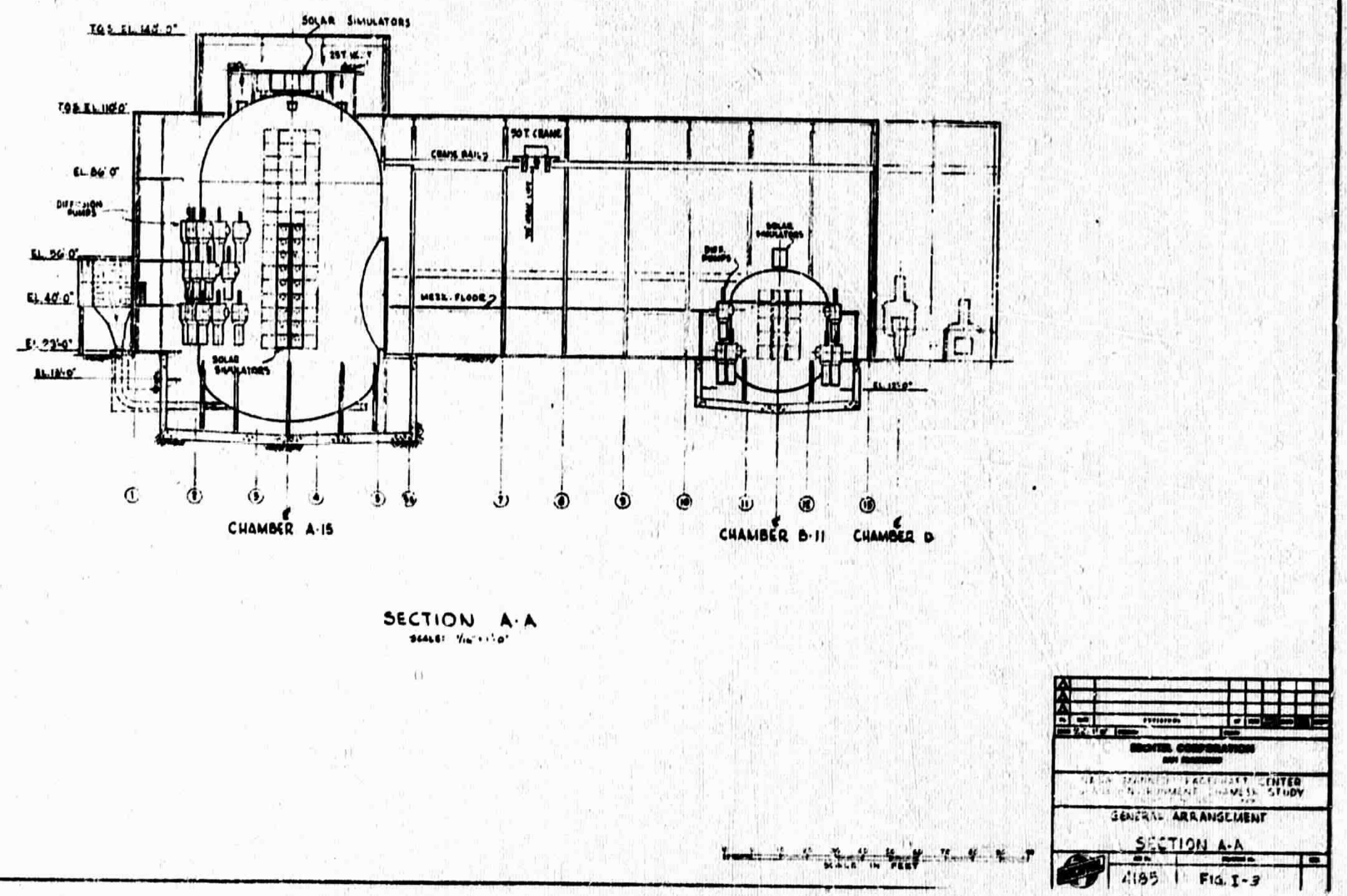
LIST OF FIGURES


N
(PLANT NORTH)
COOLING TOWER
REFRIG-ERATION BUILDING
REPRESSURIZATION
PUMP BUILDING
CHAMBER A
MAIN FACILITY BLDG
FACILITY ADMINISTRATION BUILDING
CHAMBER B
CAFETERIA
OFFICE BUILDING
FUTURE MISSION CONTROL
CENTRAL DATA
2ND STREET
LEGEND
SANITARY SEWER
FUEL GAS
WATER
STORM DRAIN
PROPOSED BORINGS
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
PLOT PLAN
4185
FIG. I-1



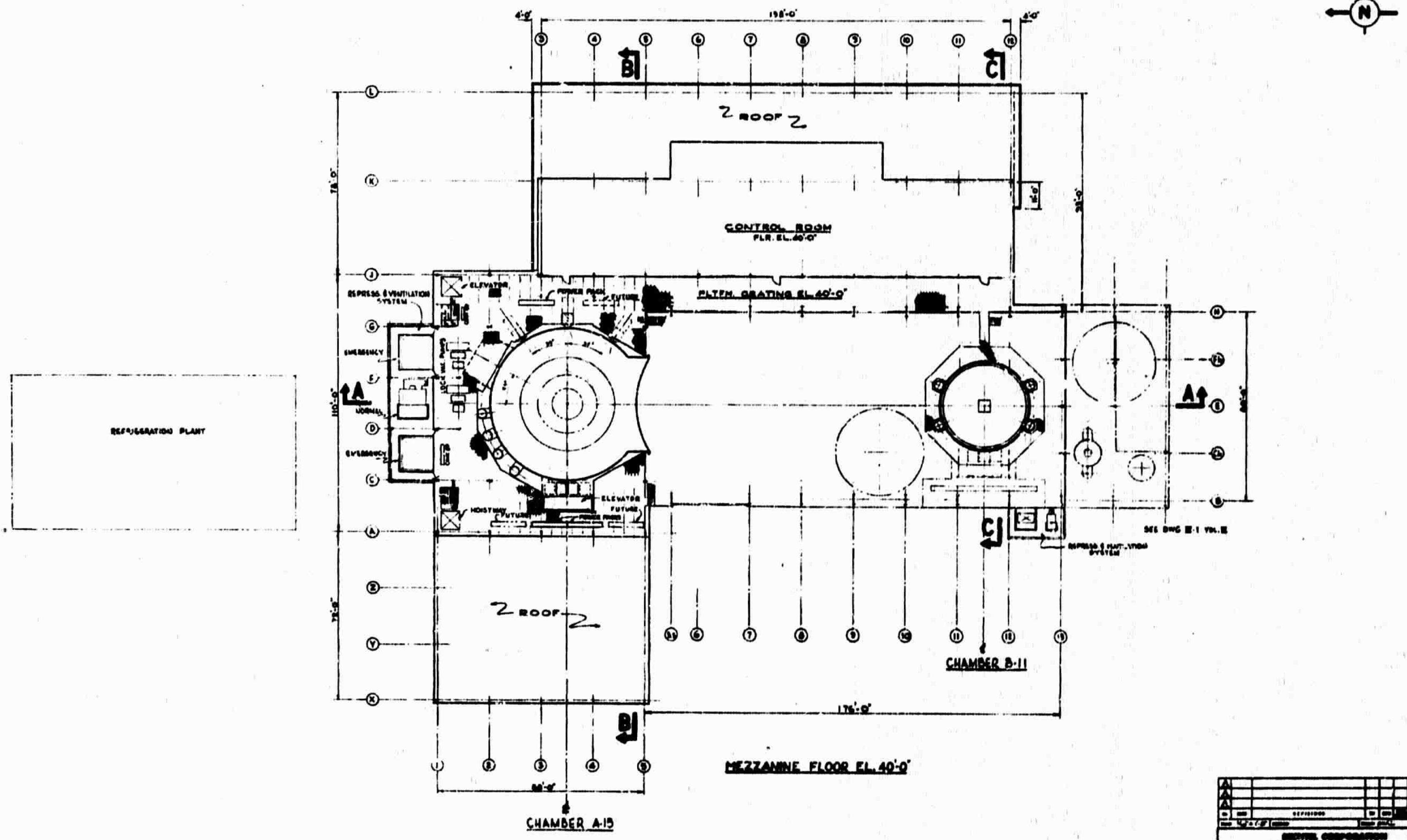
CHAMBER A-15
CHAMBER B-11
PERSONNEL AREA
REFRIGERATION PLANT
FUTURE HELIUM PLANT
FLOOR EL. 23'-0"
PORTABLE LOADING TRACK
ALT. CHAMBER B. HEAD LOCATION
TUNNEL
TURNTABLE
DOOR
LOAD CENTERS
GROUND FLOOR
EL 23'-0"
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
GENERAL ARRANGEMENT
CHAMBERS "A" & "B"
GROUND FLOOR PLAN
4186
FIG I-2
SCALE IN FEET

III



SECTION A-A
SCALE: 1/16"=1'0"

II

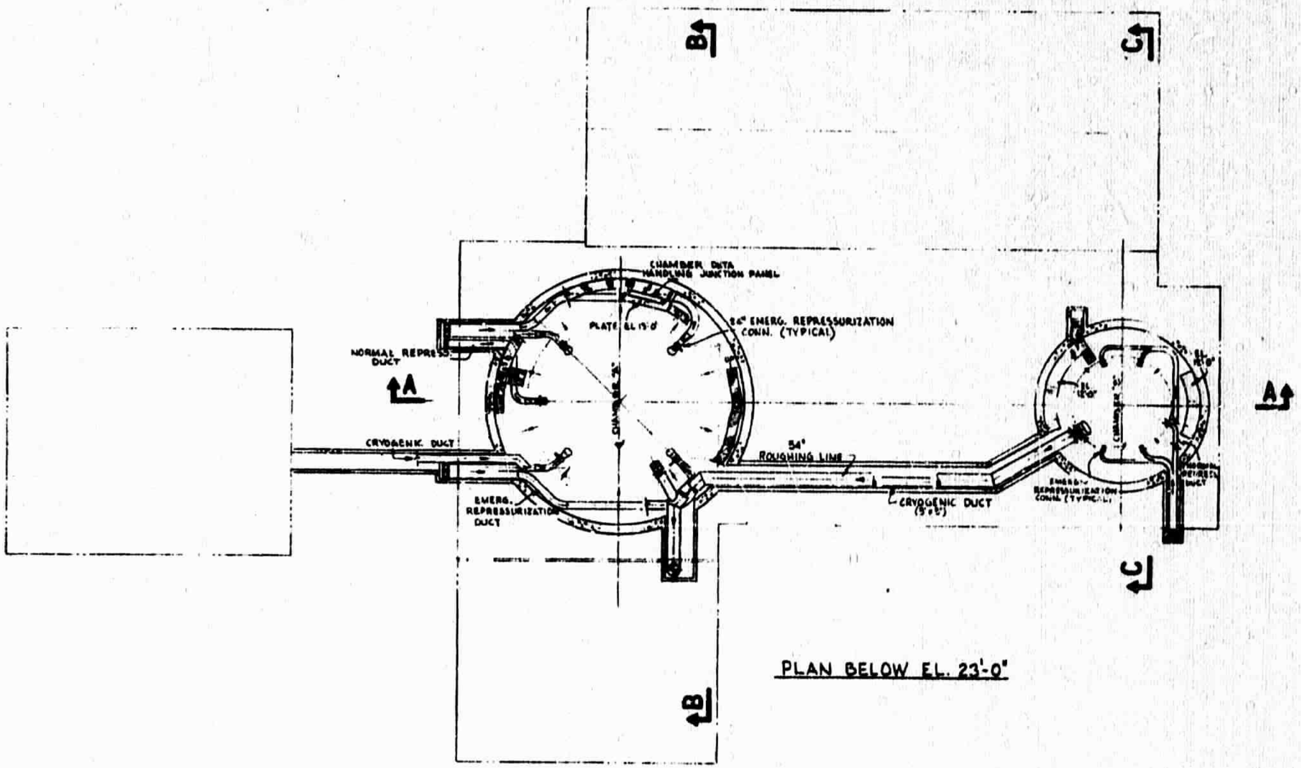


NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

GEN. ARRGT.
PLAN AT MEZZANINE FLOOR

4185 FIG I-4

II



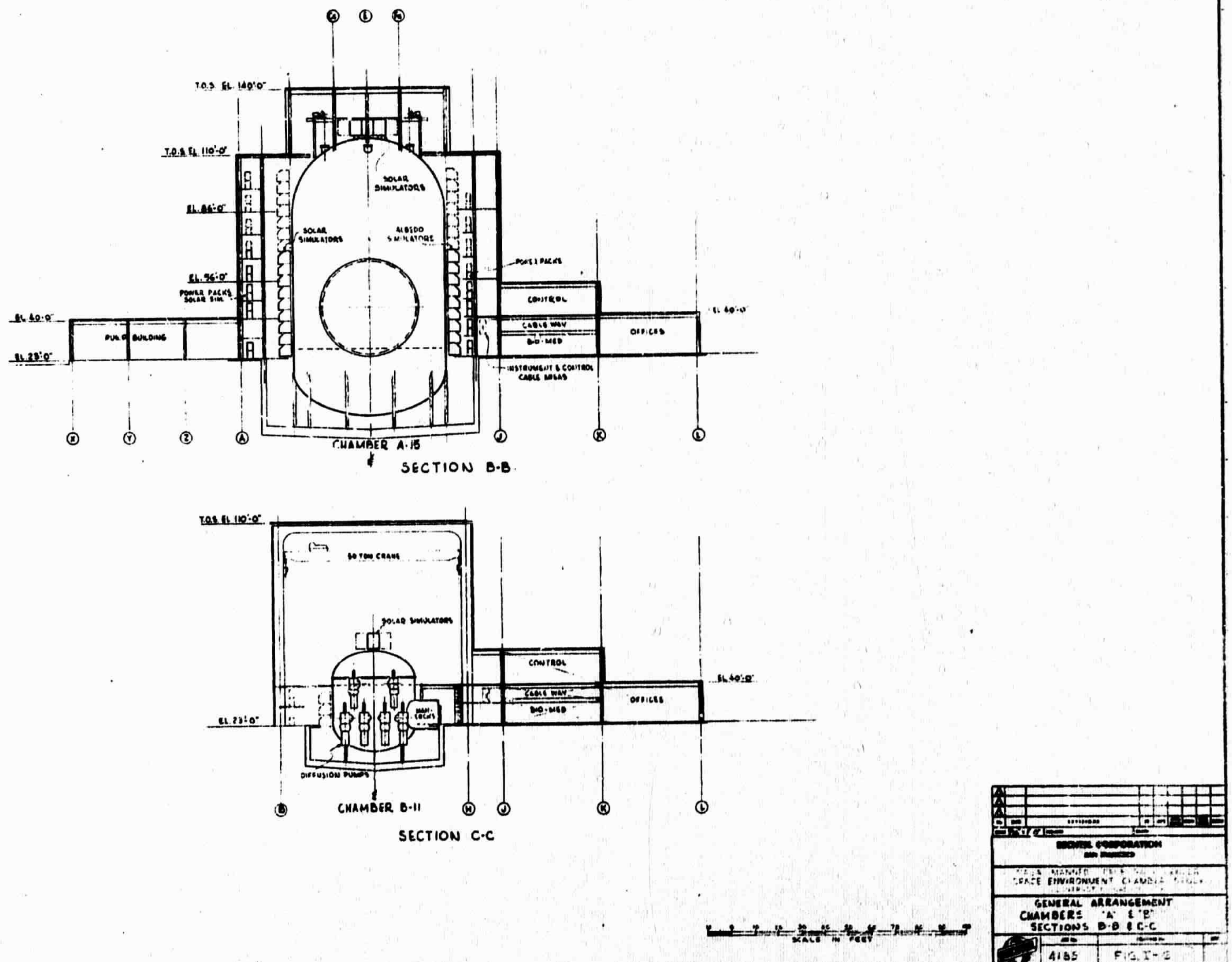
PLAN BELOW EL. 23'-0"

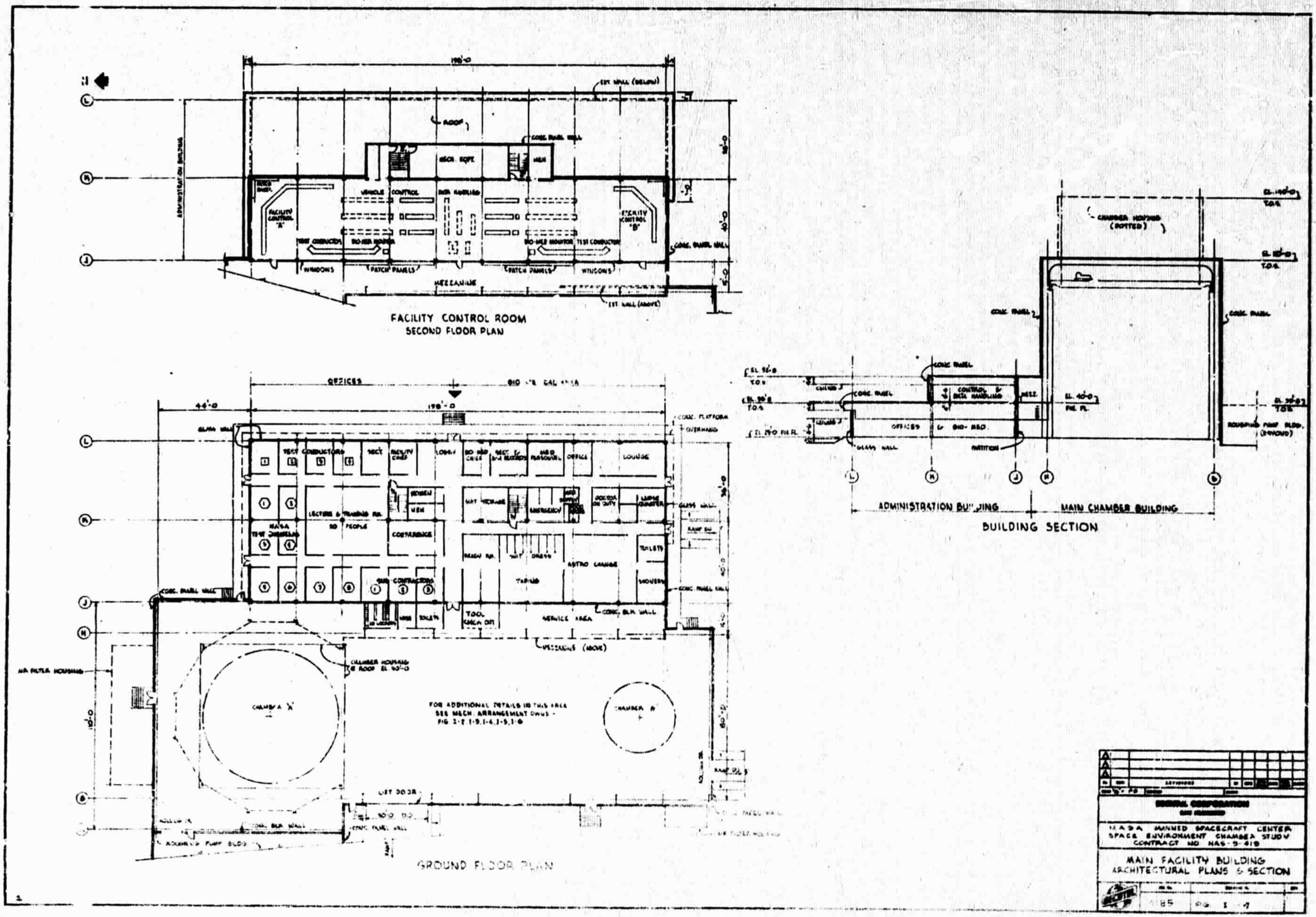
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

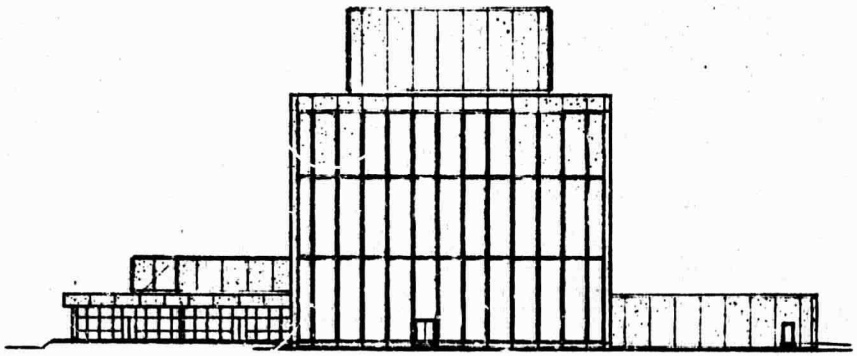
GENERAL ARRANGEMENT
TUNNELS - PLAN BELOW EL. 23'-0"

4185 | FIG. 1-5

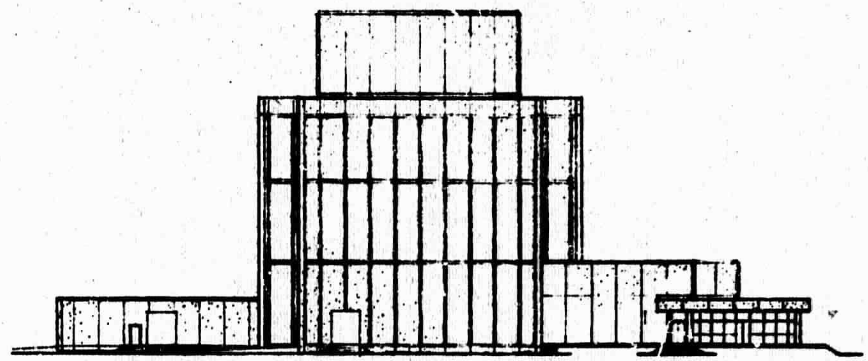
III


T.O.S. EL. 140'-0"
T.O.S EL 110'-0"
EL 86'-0"
SOLAR SIMULATORS
ALBEDO SIMULATORS
EL 56'-0"
POWER PACKS SOLAR SIM.
POWER PACKS
CONTROL
CABLE WAY
BIO-MED
OFFICES
PUMP BUILDING
EL 40'-0"
EL 23'-0"
INSTRUMENT & CONTROL CABLE AREAS
CHAMBER A-15
SECTION B-B
T.O.S EL 110'-0"
50 TON CRANE
SOLAR SIMULATORS
MAN-LOCKS
DIFFUSION PUMPS
CHAMBER B-11
SECTION C-C
SCALE IN FEET
GENERAL ARRANGEMENT
CHAMBERS 'A' & 'B'
SECTIONS B-B & C-C
SPACE ENVIRONMENT CHAMBER
4185
FIG. I-8

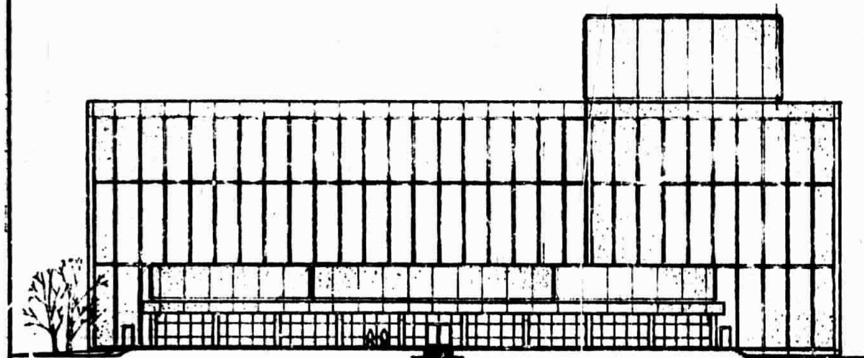

FACILITY CONTROL ROOM
SECOND FLOOR PLAN
GROUND FLOOR PLAN
BUILDING SECTION
ADMINISTRATION BUILDING
MAIN CHAMBER BUILDING
OFFICES
LOUNGE
TEST CONDUCTORS
LECTURE & TRAINING RM.
50 PEOPLE
CONFERENCE
TAPING
ASTRO CHANGE
SERVICE AREA
TOILETS
SHOWERS
CHAMBER 'A'
CHAMBER 'B'
FOR ADDITIONAL DETAILS IN THIS AREA SEE MECH. ARRANGEMENT DWGS - FIG. 3-2.1-9.1-4.1-5.1-6
VEHICLE CONTROL
DATA HANDLING
MECH. EQPT.
MEZZANINE
WINDOWS
PATCH PANELS
CHAMBER HOUSING (DOTTED)
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NO NAS-9-419
MAIN FACILITY BUILDING
ARCHITECTURAL PLANS & SECTION



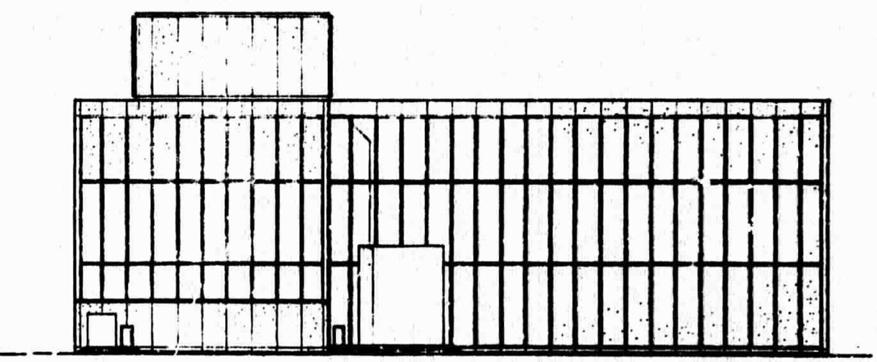
NORTH ELEVATION



SOUTH ELEVATION



EAST ELEVATION

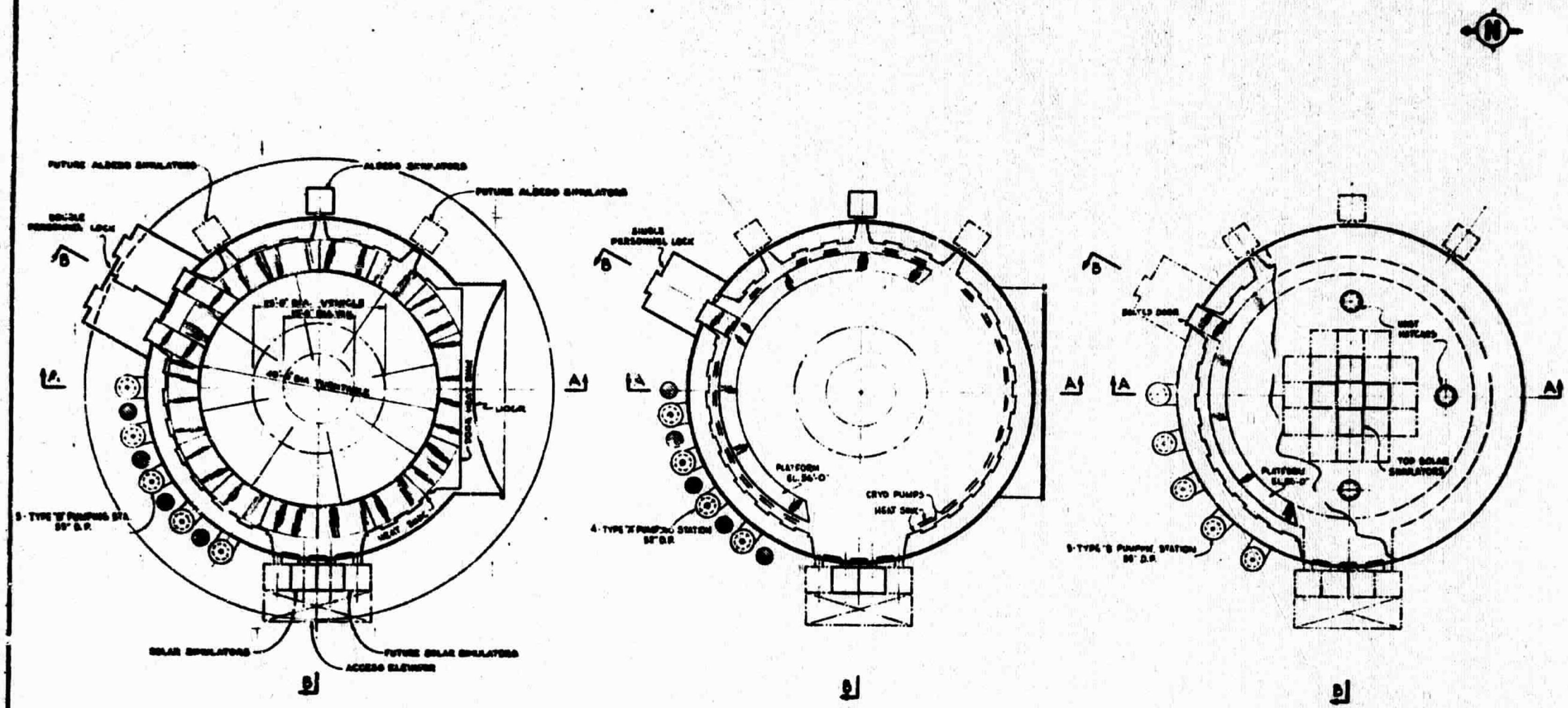


WEST ELEVATION

N A S A SPACECRAFT CENTER
CONTRACT NO.

MAIN FACILITY BUILDING
ARCHITECTURAL ELEVATIONS

4185



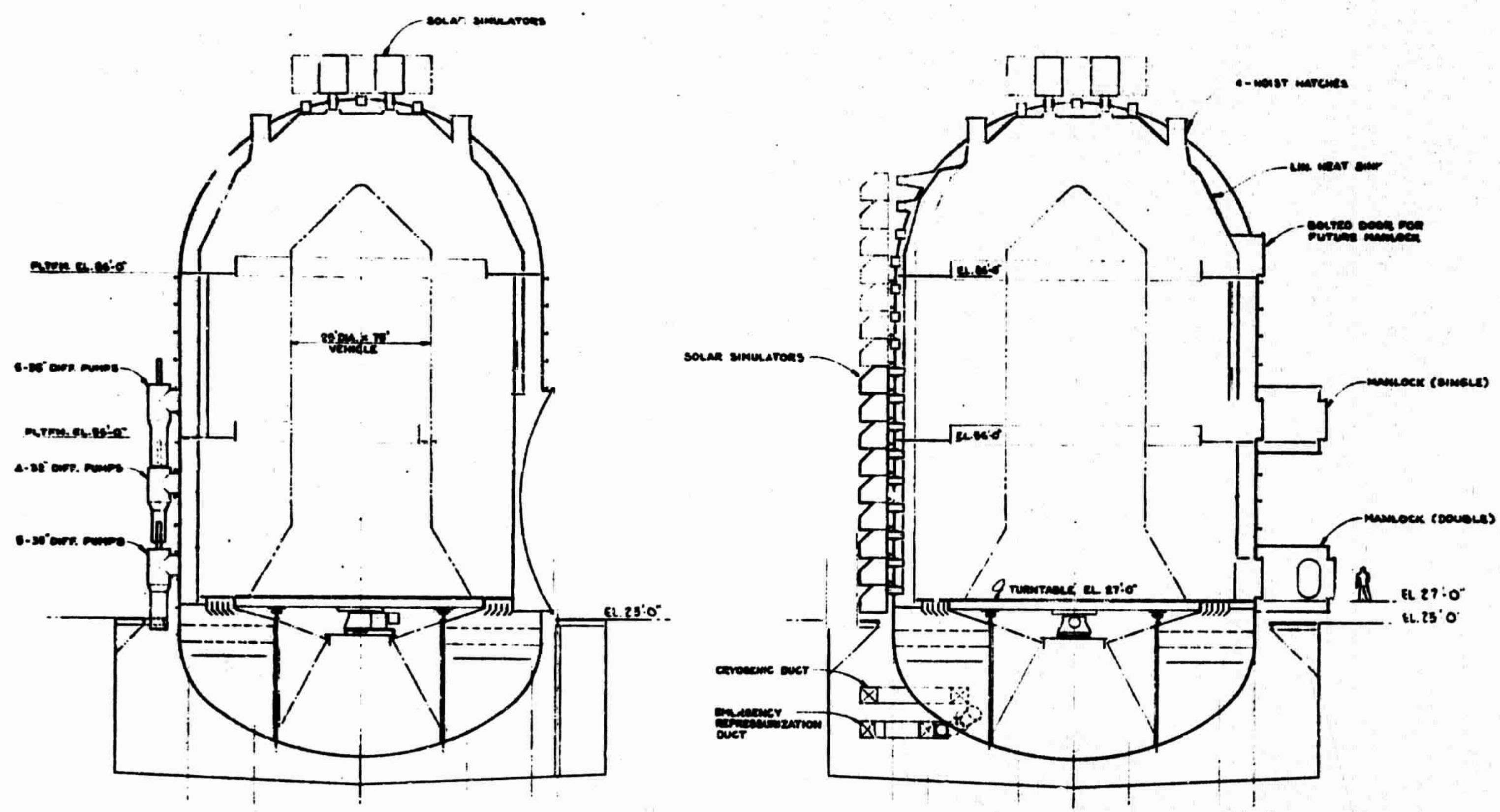
PLAN OF EL. 27'-0"

PLAN OF EL. 56'-0"

TOP PLAN & EL. 86'-0"

NASA - MSC
HOUSTON, TEXAS
GENERAL ARRANGEMENT
CHAMBER A
PLANS

4183 | FIG. II-1



SECTION A-A

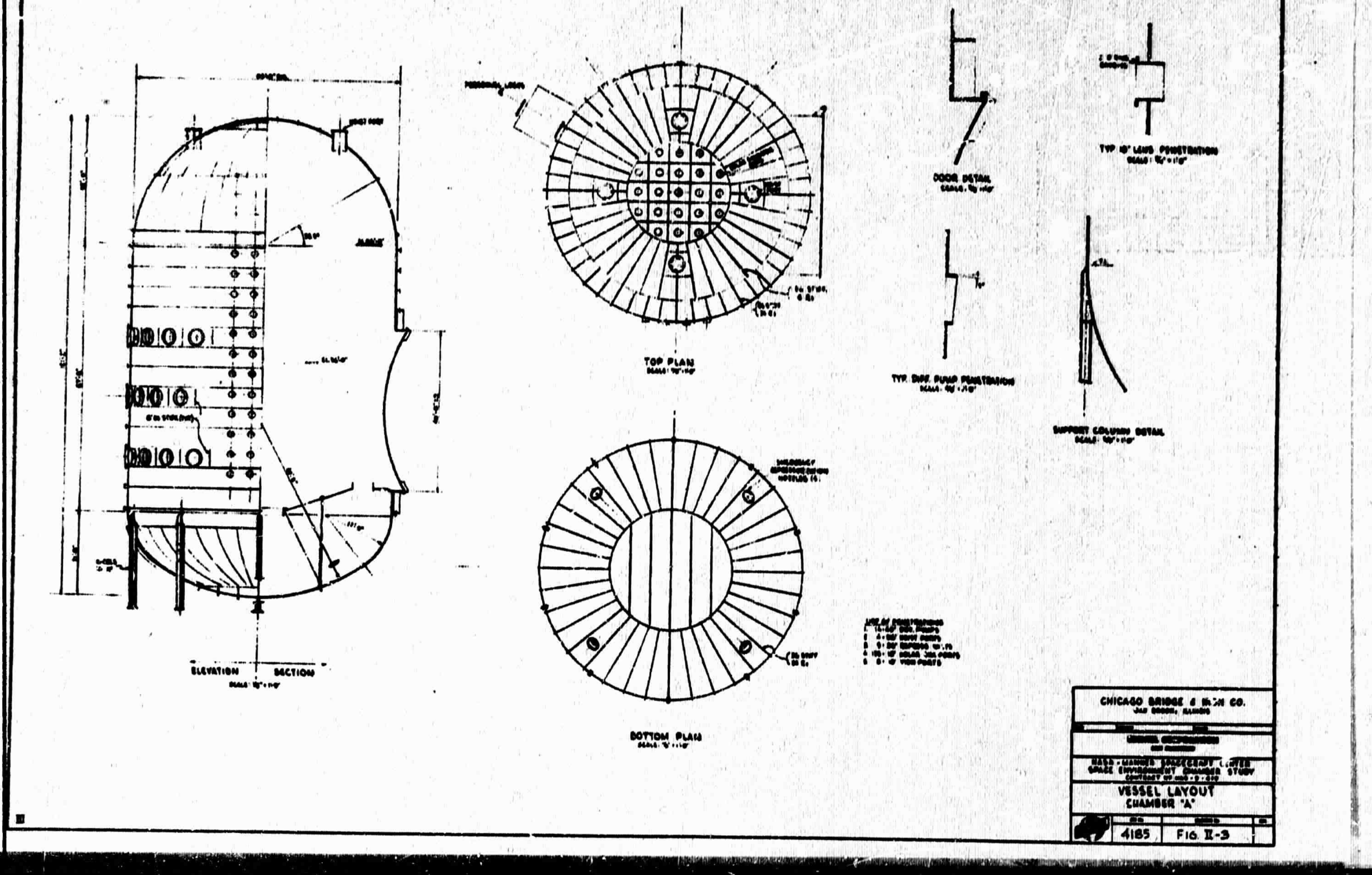
SECTION B-B

NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

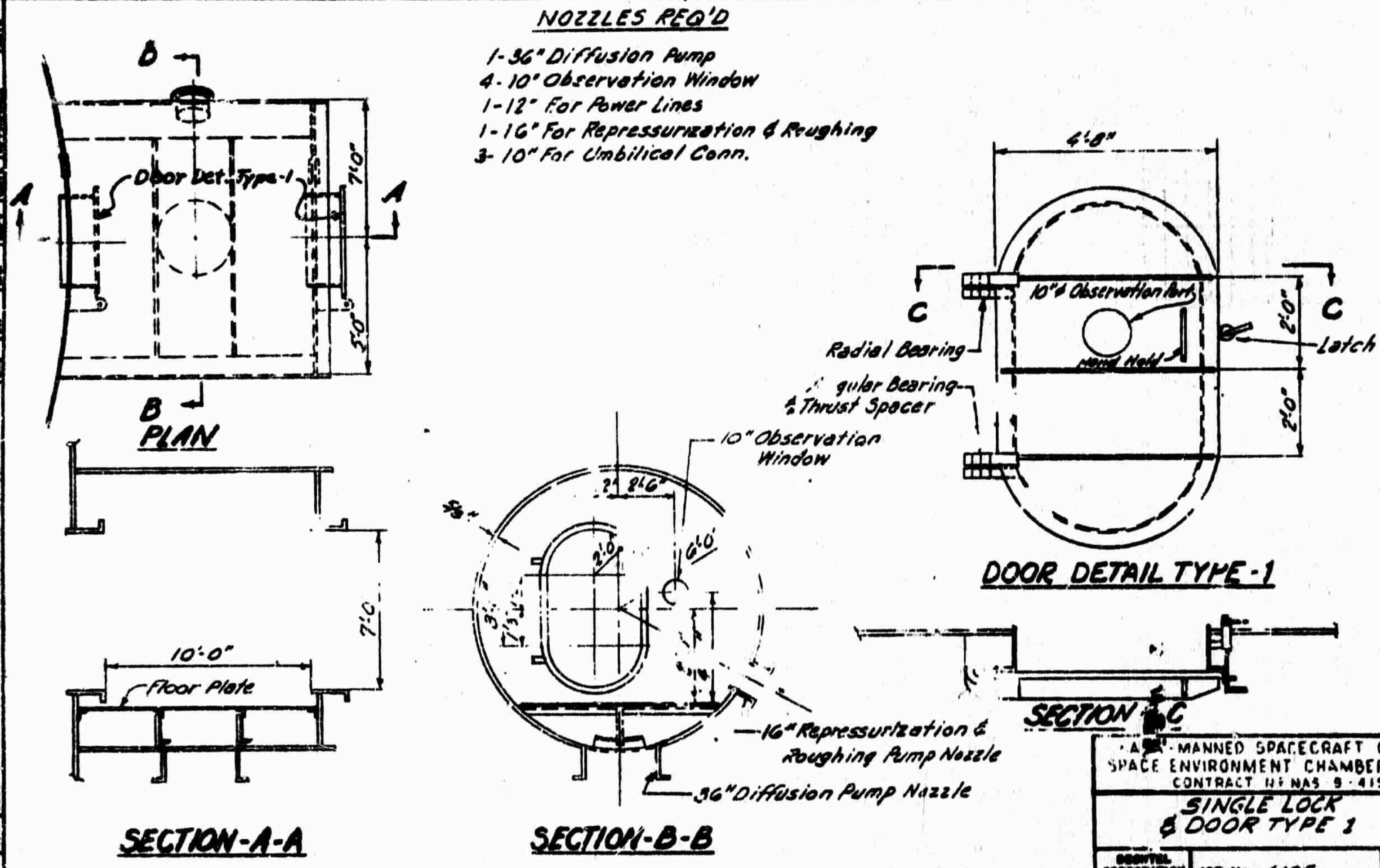
GENERAL ARRANGEMENT
CHAMBER-A
SECTION - A-A & B-B

4185

FIG. II-2



ELEVATION SECTION
TOP PLAN
BOTTOM PLAN
DOOR DETAIL
TYP. 10" LENS PENETRATION
TYP. DIFF. PUMP PENETRATION
SUPPORT COLUMN DETAIL
CHICAGO BRIDGE & IRON CO.
VESSEL LAYOUT
CHAMBER "A"
4185
FIG. II-3



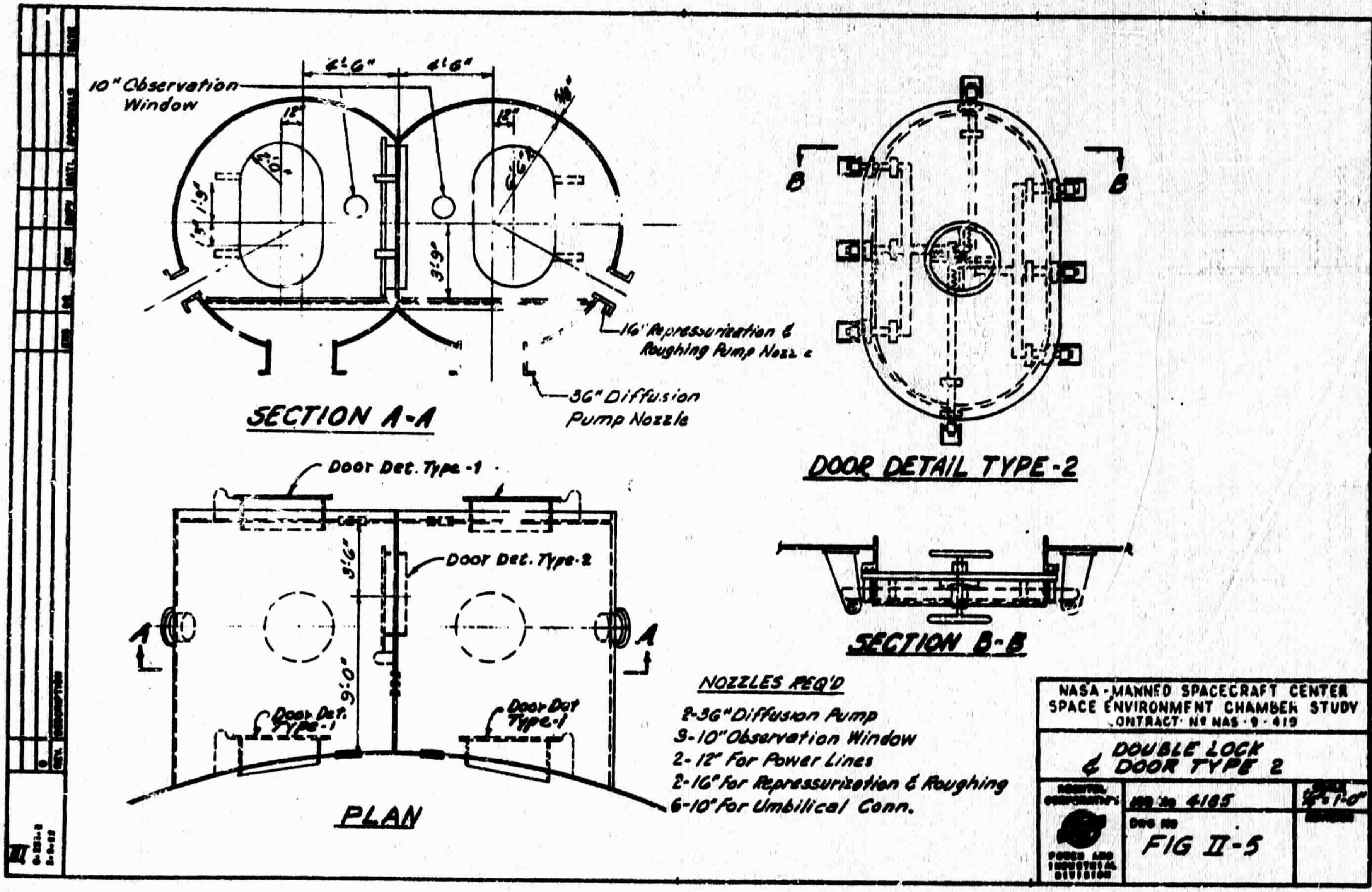
MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NAS 9-419

SINGLE LOCK & DOOR TYPE 1

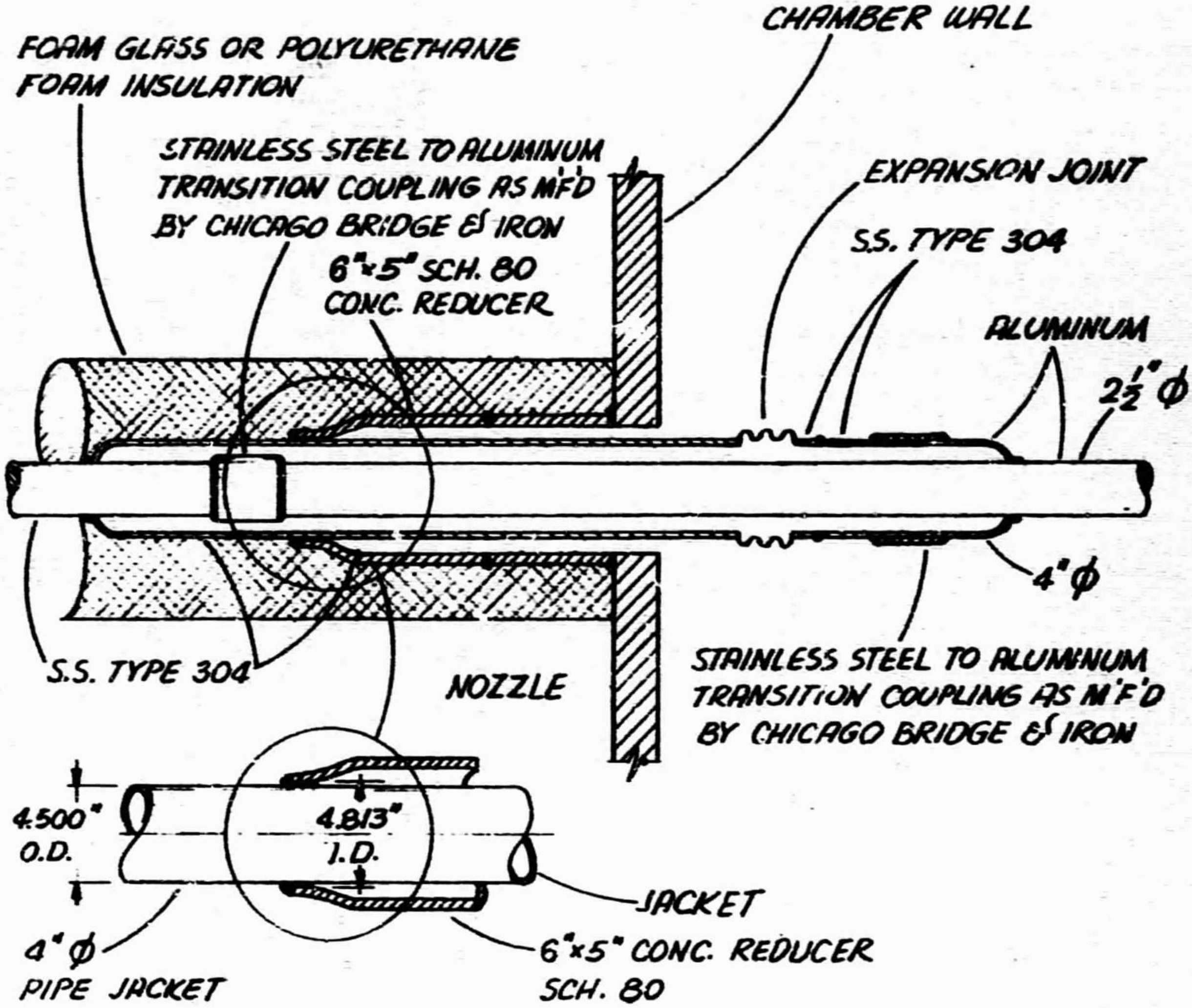
JOB No 4185 | SCALE 1/4" = 1'-0"

DWG NO FIG. II-4

POWER AND INDUSTRIAL DIVISION



10" Observation Window
4'-6"
4'-6"
12"
3'-9"
16" Repressurization & Roughing Pump Nozzle
36" Diffusion Pump Nozzle
SECTION A-A
B
B
DOOR DETAIL TYPE-2
SECTION B-B
Door Det. Type-1
Door Det. Type-2
Door Det. Type-1
Door Det. Type-1
9'-6"
9'-0"
A
A
PLAN
NOZZLES REQ'D
2-36" Diffusion Pump
9-10" Observation Window
2-12" For Power Lines
2-16" For Repressurization & Roughing
6-10" For Umbilical Conn.
NASA-MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT Nº NAS-9-419
DOUBLE LOCK & DOOR TYPE 2
4185
FIG II-5

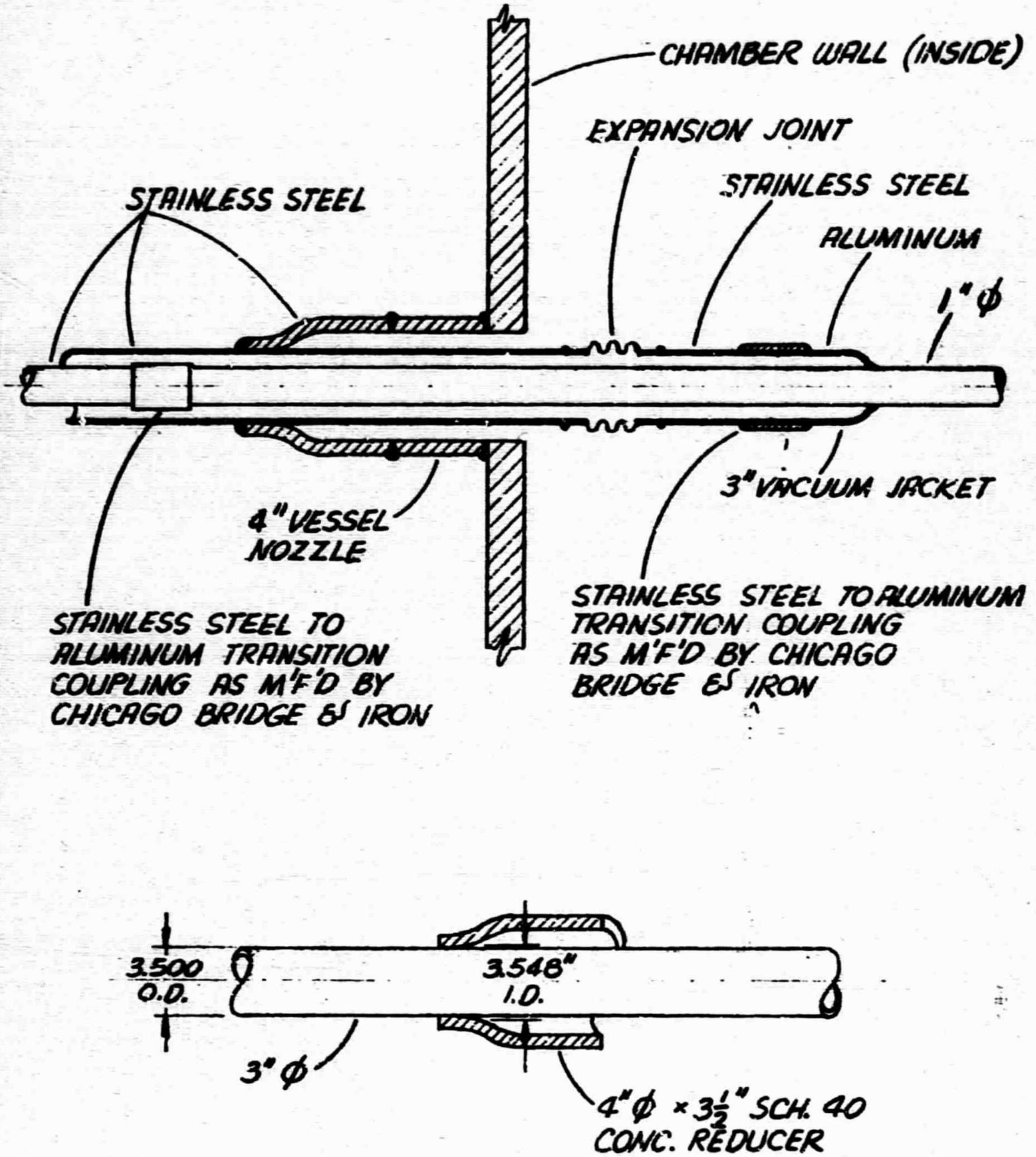


PIPE SPECIFICATIONS

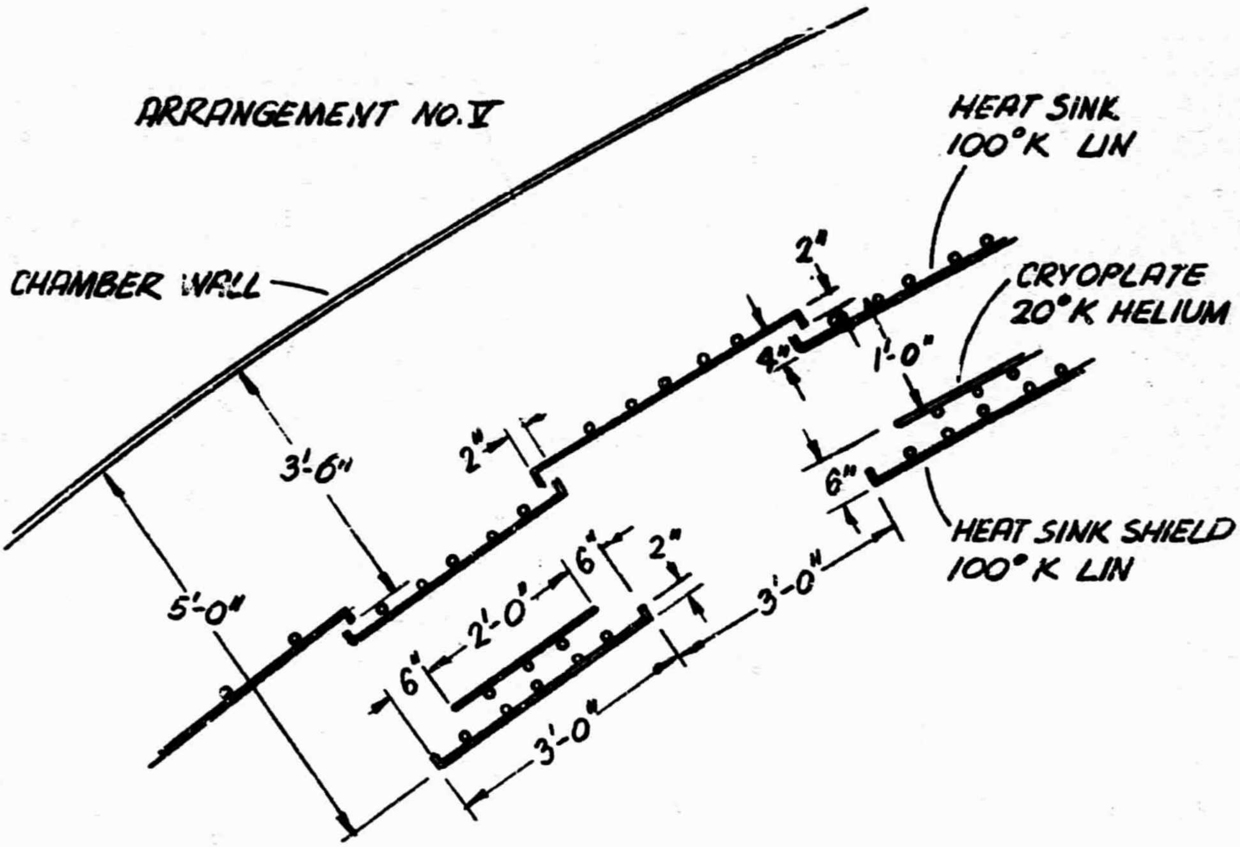
ALUMINUM - 100°F AND BELOW - 300 PSIG - MAX. OWG.
2" THROUGH 4" - STD. WT. SMLSS - ASTM - B-241 M1A.
6" THROUGH 8" - XH SMLSS - ASTM - B-241 M1A.

STAINLESS STEEL - 100°F AND BELOW - 1200 PSIG - MAX. OWG.
$\frac{1}{4}$" THROUGH 8" - SCH. 40 - ASTM A-312 TYPE 304

BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT No NAS-9-419	JOB No 4185
	TYPICAL LIQUID NITROGEN PIPE PENETRATION OF CHAMBER WALL	FIG. II-6



BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT Nº NAS - 9 - 419	JOB No 4185	REV.
	TYPICAL HELIUM PIPE PENETRATION OF CHAMBER WALL	FIG. II - 7	



REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
0	0							

G-231-E 4-14-59 III

BECHTEL CORPORATION
POWER AND INDUSTRIAL DIVISION

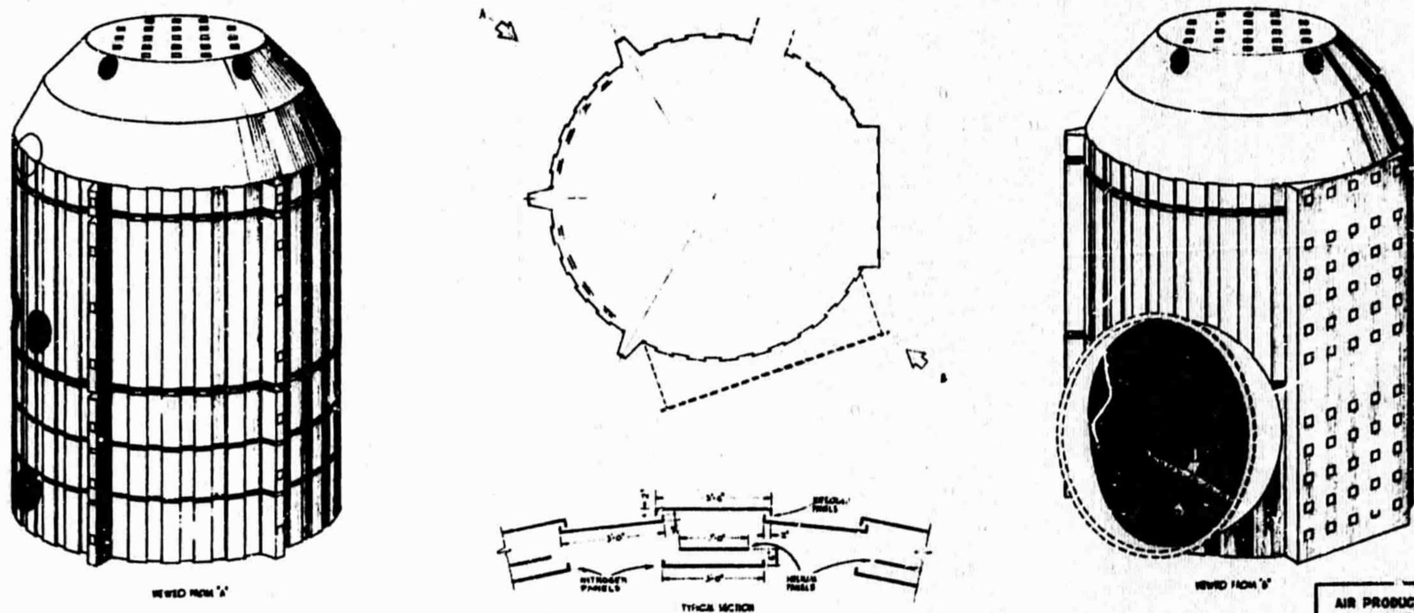
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT Nº NAS - 9 - 419

PREFERRED HEAT SINK AND CYROPUMP CONFIGURATION

JOB No 4185

FIG. II - 8

REV.



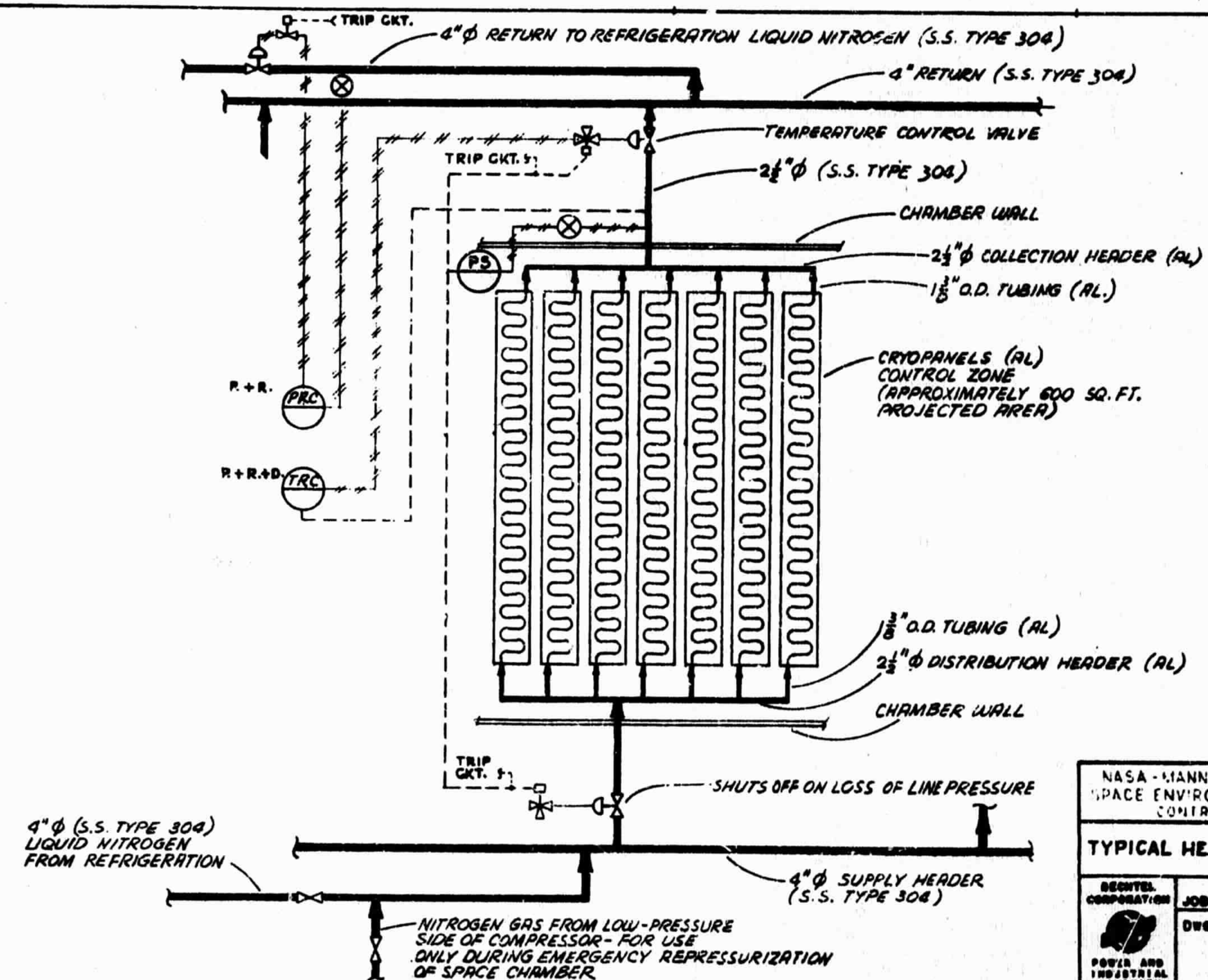
AIR PRODUCTS AND CHEMICALS, INC.
ALLENTOWN, PENN.

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

CHAMBER A - ISOMETRIC
CRYOGENIC PANEL ARRGT.

4185 | FIG. II-9

III



NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NO NAS 9-419

TYPICAL HEAT SINK CONTROL ZONE

BECHTEL CORPORATION
POWER AND INDUSTRIAL DIVISION

JOB No 4183

DWG NO

FIG. II-10

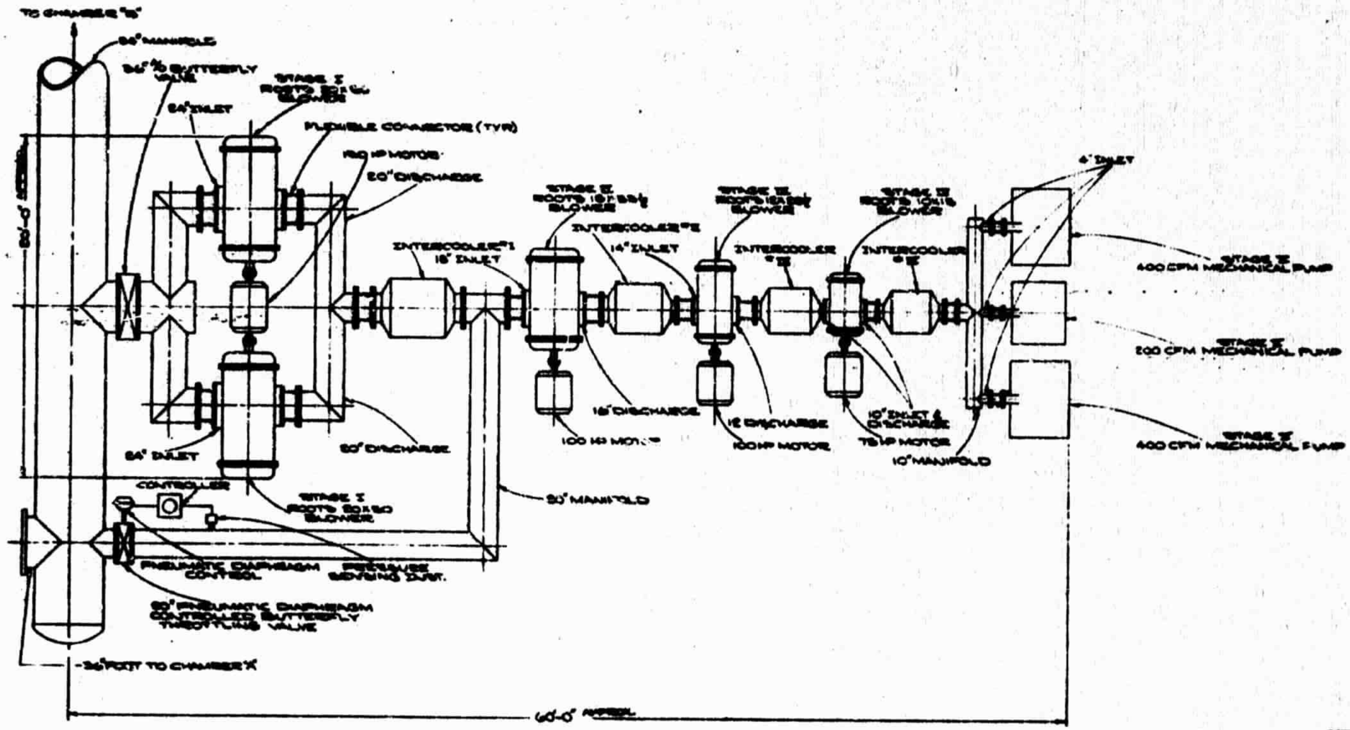
SCALE

REVISION

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MAT'L	APPROVALS	DATE
0								

III

G-231-B
3-3-62

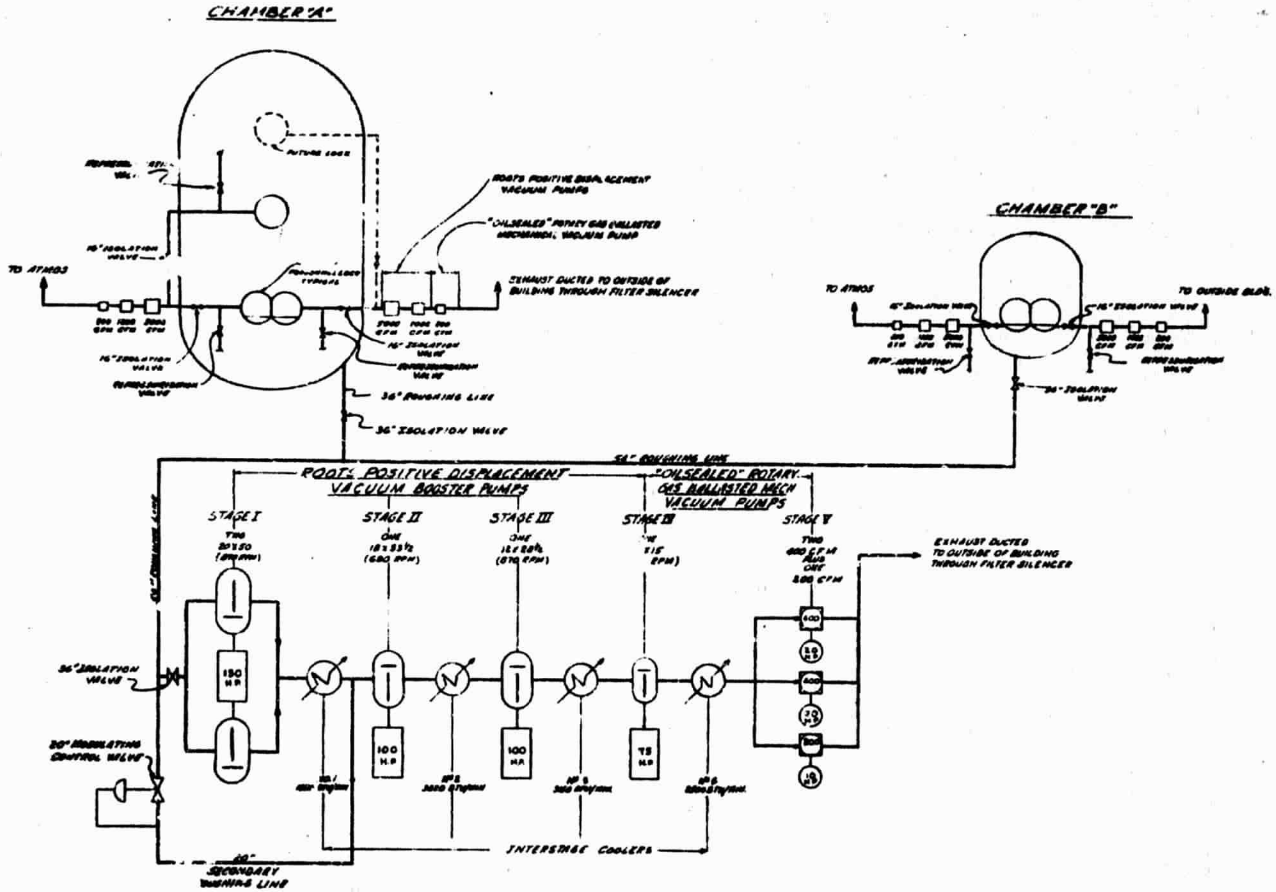


NATIONAL RESEARCH CORP.

NASA MANNED SPACECRAFT CENTER - SPACE ENVIRONMENT CHAMBER STUDY

MECHANICAL PUMPING ARRGT - ROUGHING SYSTEM

4185 FIG II-11



NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

SCHEMATIC DIAGRAM
ROUGHING PUMP SYSTEM

4185 FIG. II-12

III

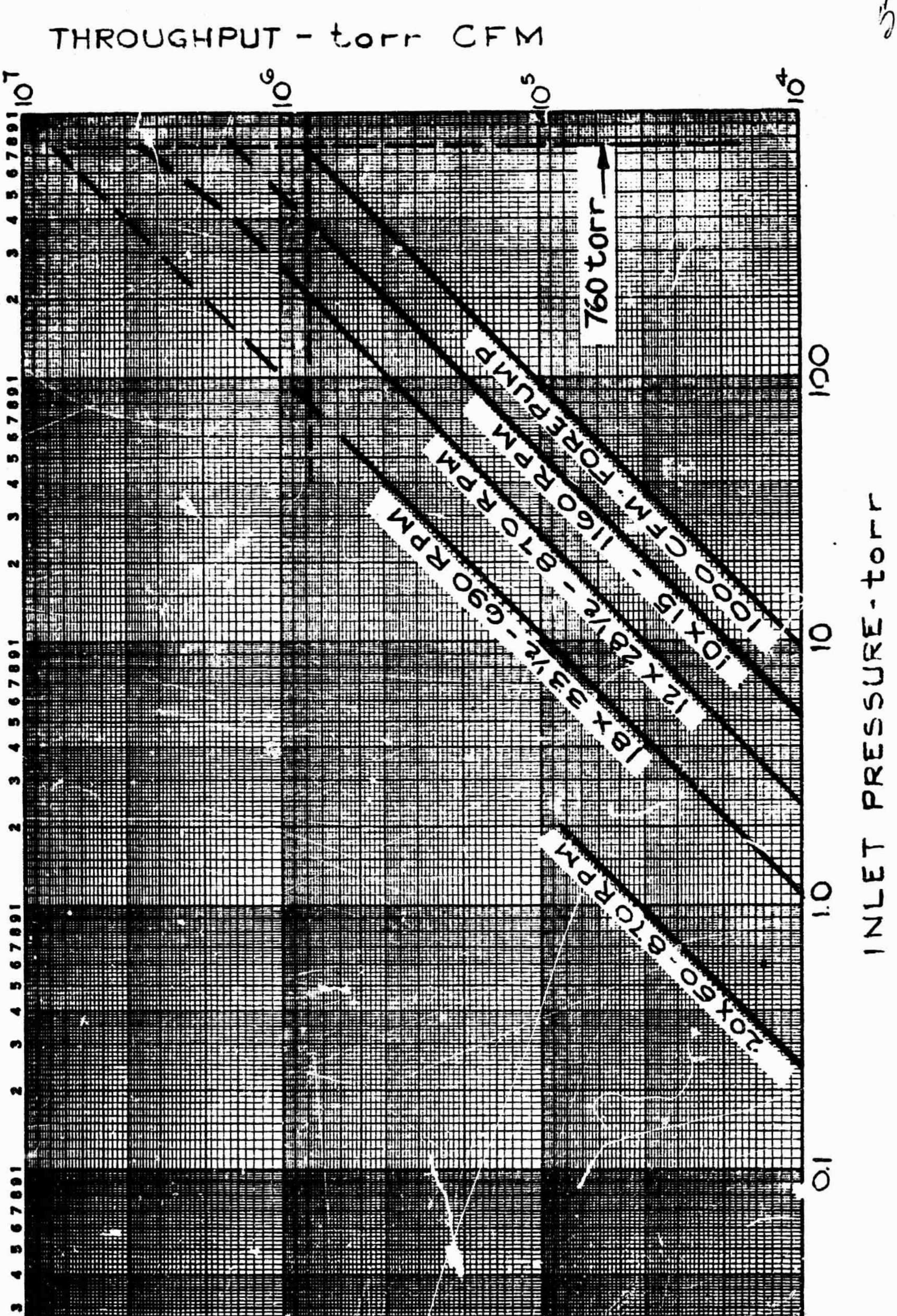
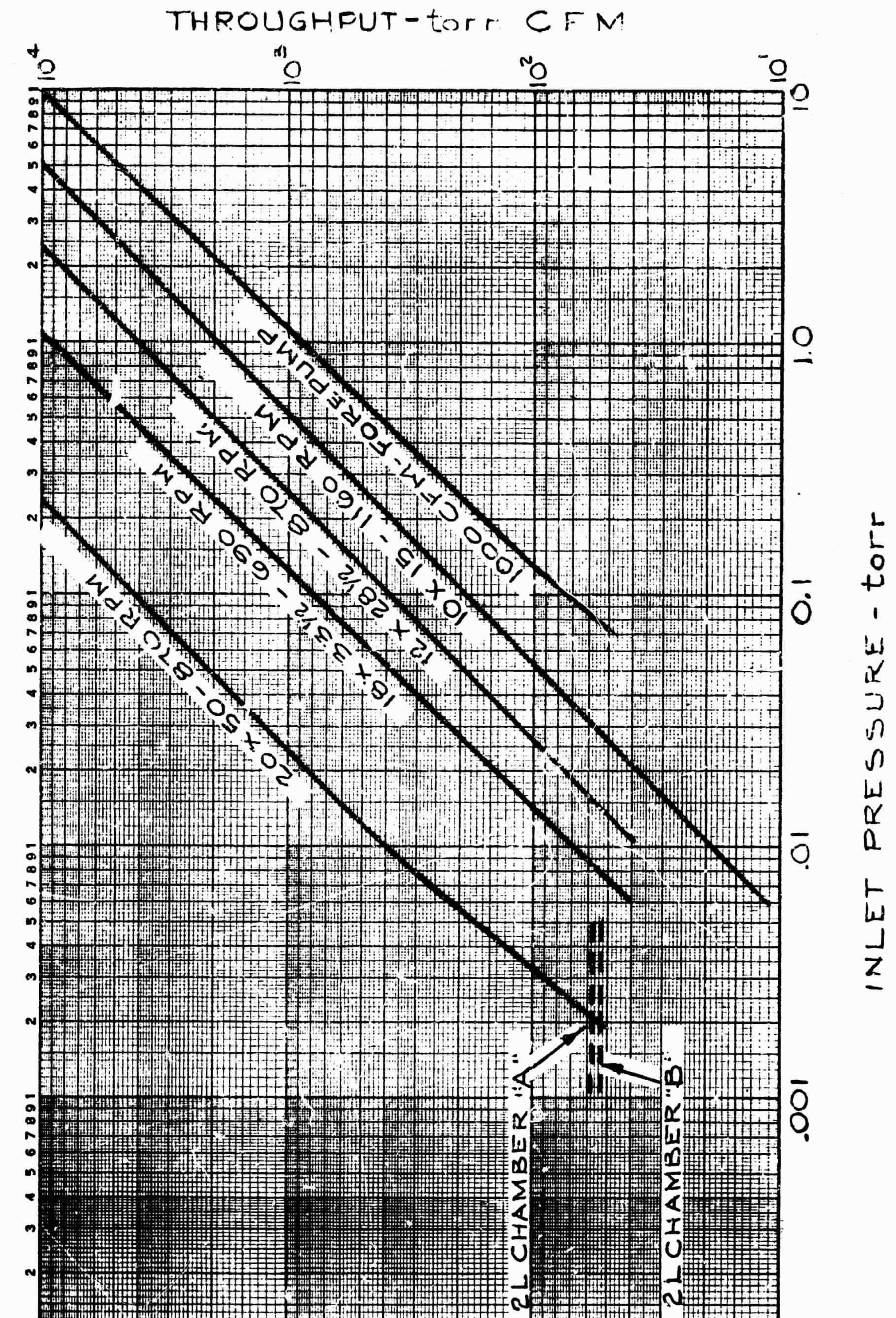
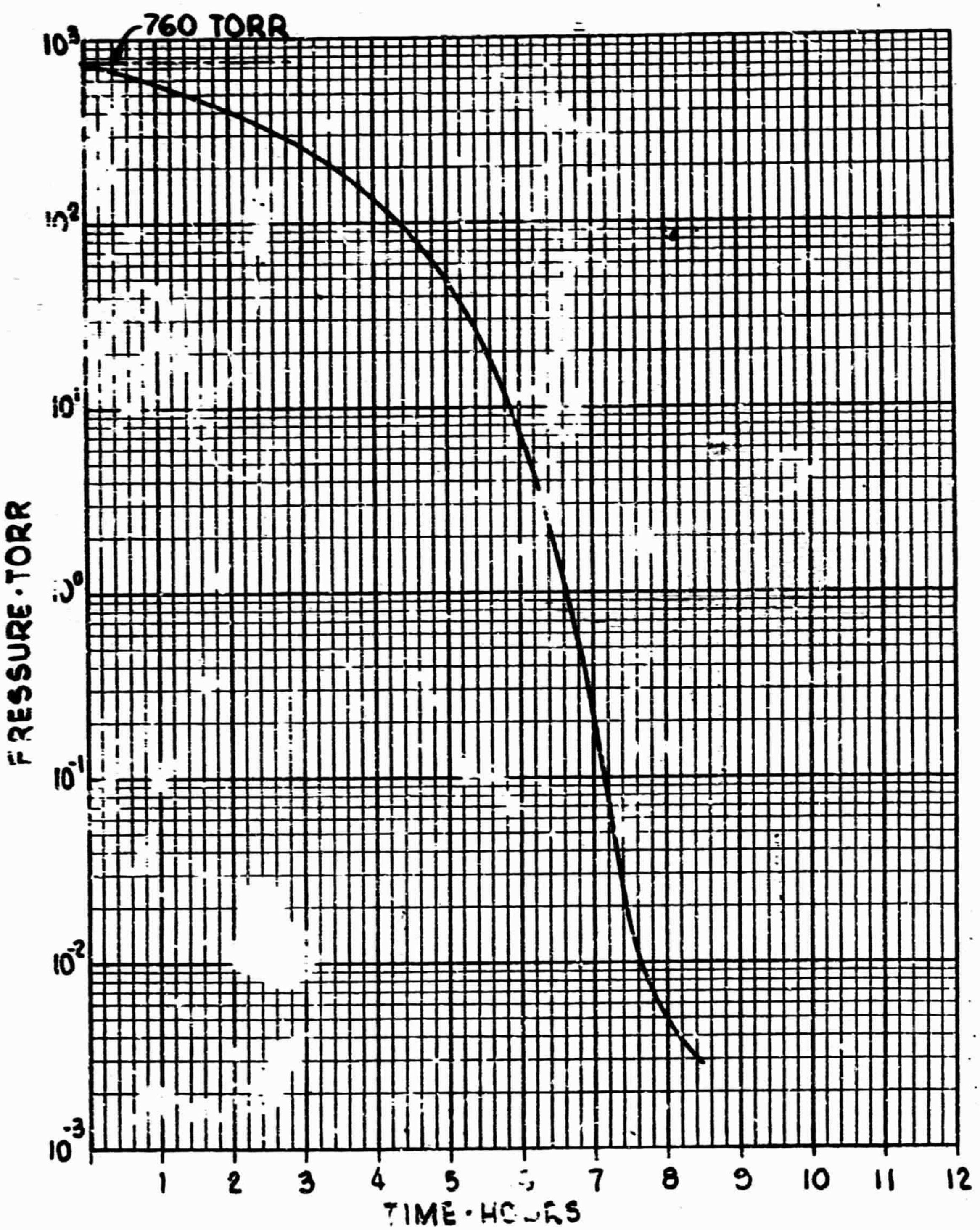

THROUGHPUT - torr CFM
10^7
10^6
10^5
10^4
760 torr
1000 CFM. FOREPUMP
10X15 - 1160 RPM
12X28½ - 870 RPM
18X33½ - 690 RPM
20X60 - 870 RPM
100
10
1.0
0.1
INLET PRESSURE - torr

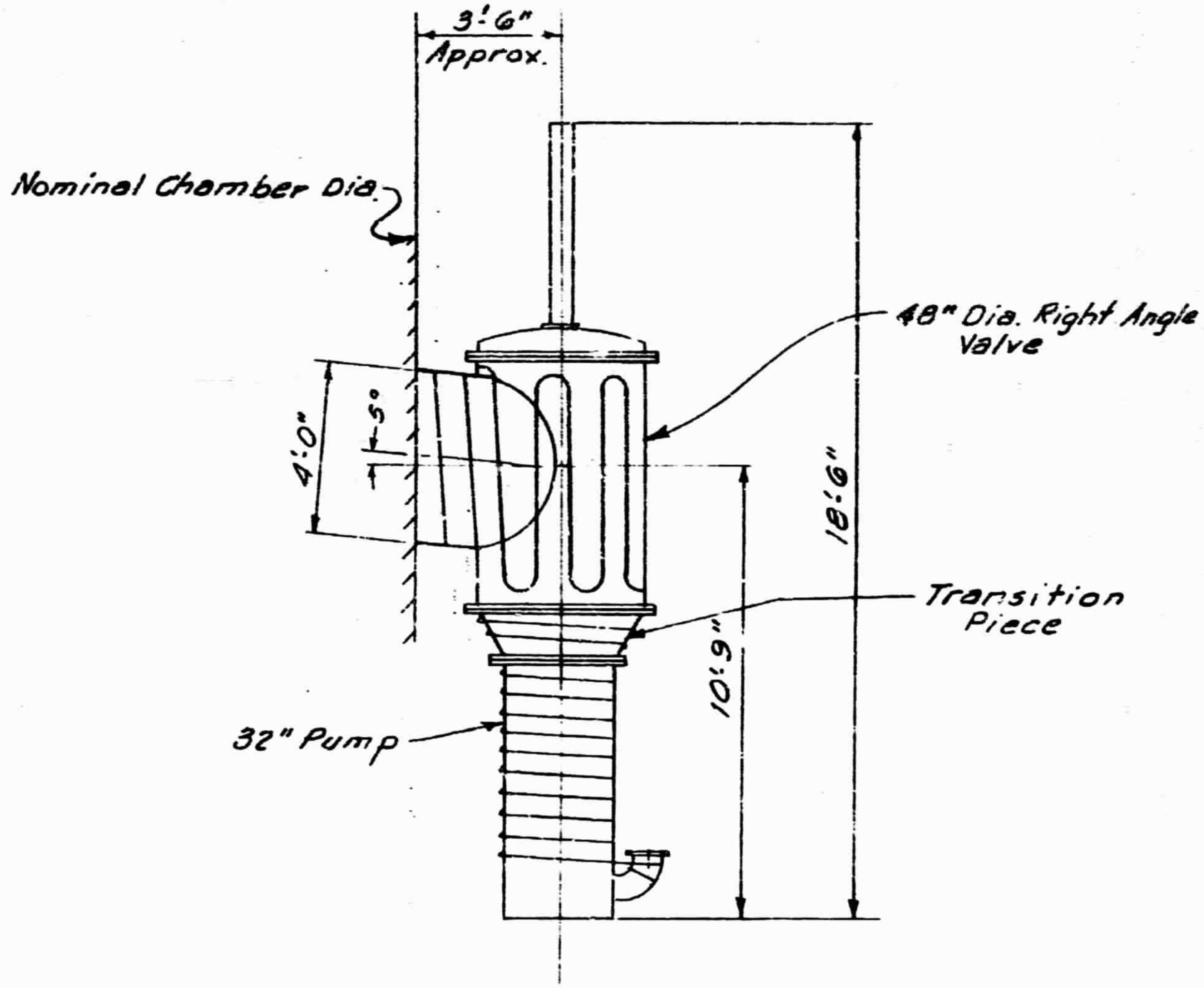
FIG. II-13


THROUGHPUT - torr CFM
10^4
10^3
10^2
10^1
10
1.0
0.1
.01
.001
INLET PRESSURE - torr
1000 CFM - FOREPUMP
10 X 15 - 1160 RPM
12 X 28½ - 870 RPM
18 X 33½ - 690 RPM
20 X 50 - 870 RPM
2L CHAMBER "A"
2L CHAMBER "B"
K+E LOGARITHMIC 358-125
KEUFFEL & ESSER CO. MADE IN U.S.A.
3 X 5 CYCLES



CHAMBER A-12 ROUGHING PUMP DOWN CURVE

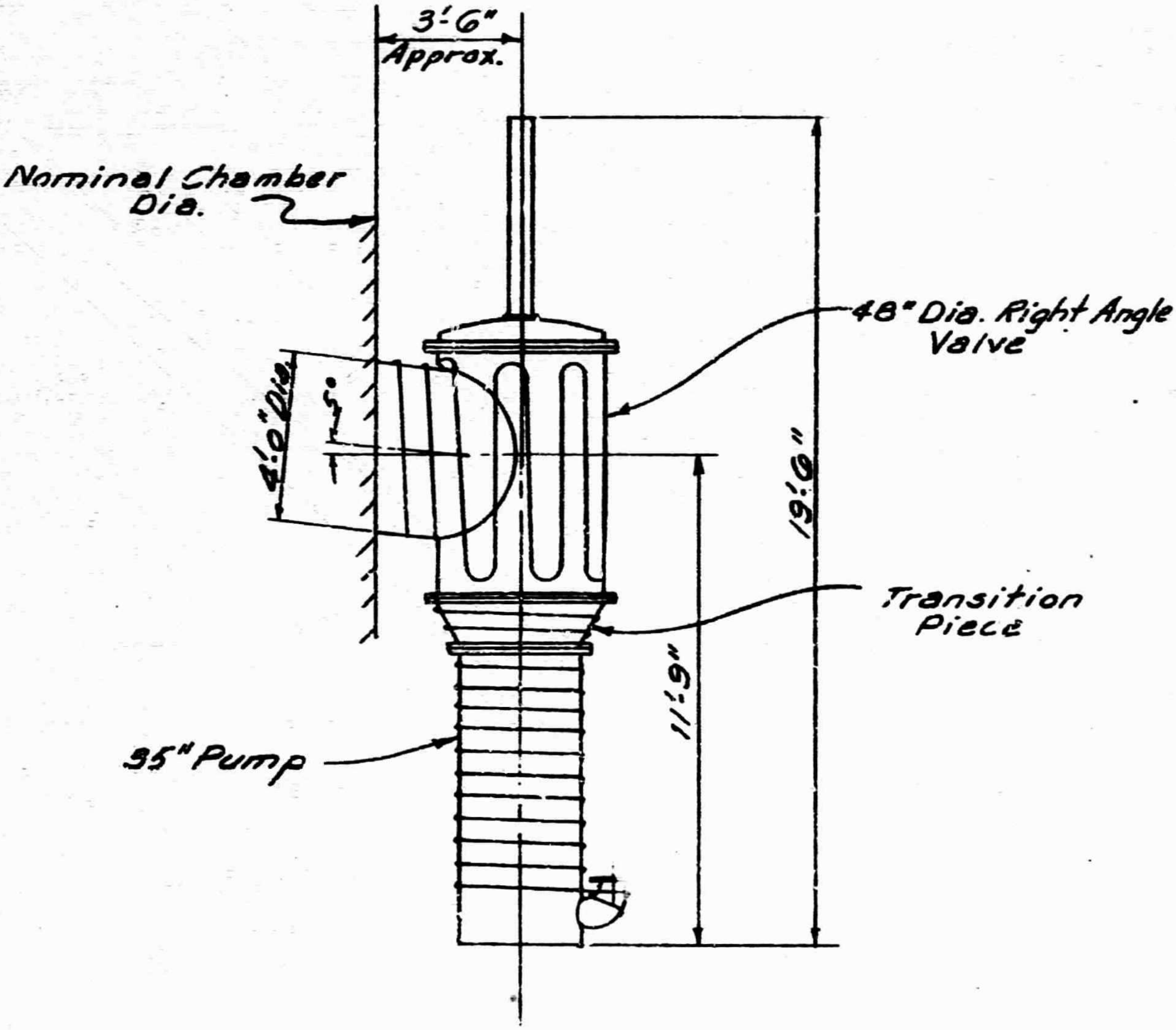
FIG II-15



BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT Nº NAS - 9 - 419	JOB No 4185
	TYPE "A" PUMPING STATION	FIG. II-16

REV. DESCRIPTION ENG DR CHK SUPV MATL APPROVALS DATE

G-231-E
III



BECHTEL CORPORATION
POWER AND INDUSTRIAL DIVISION

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT No NAS - 9 - 419

JOB No 4185

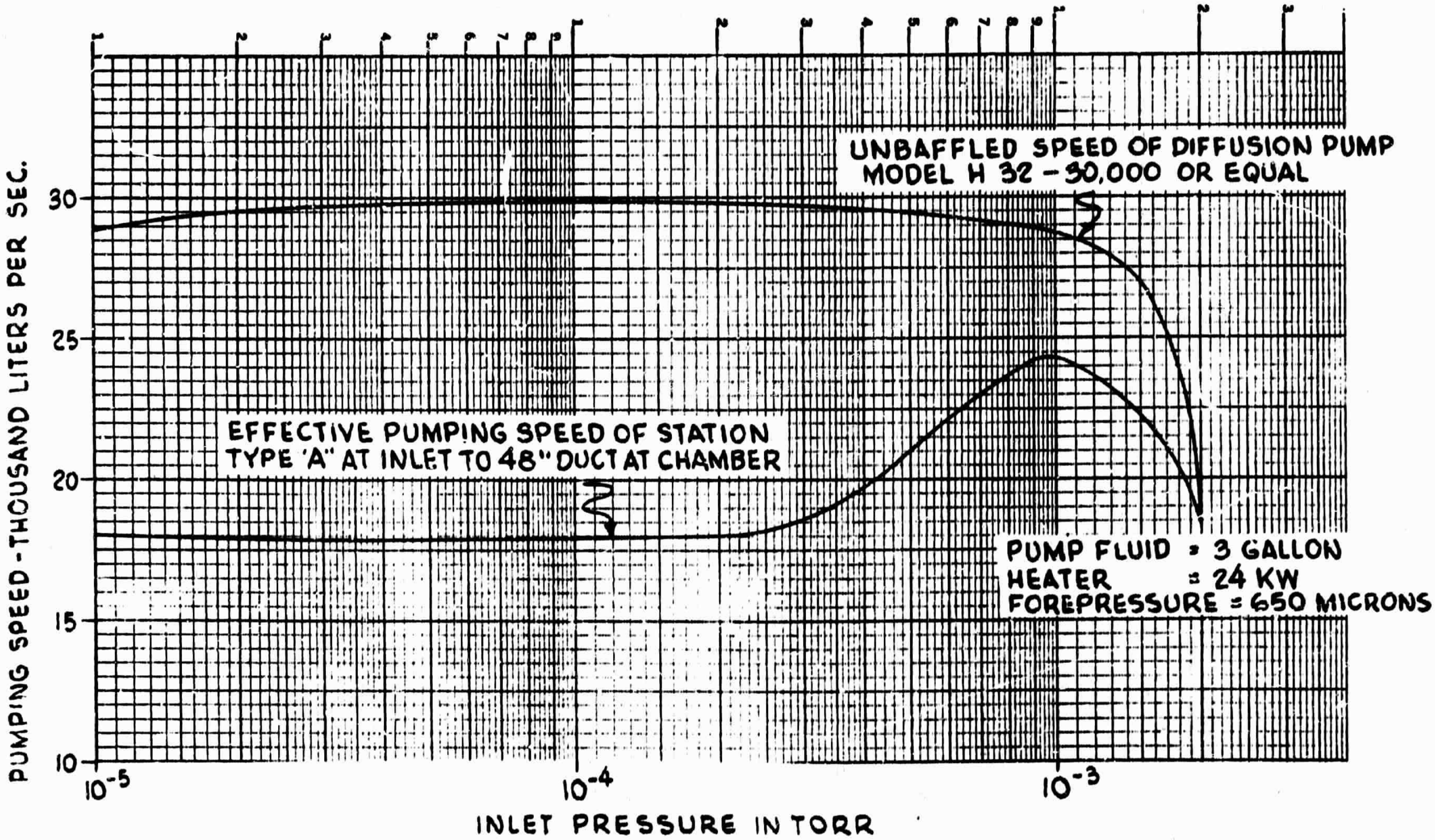
TYPE "B" PUMPING STATION

FIG. II-17

REV.

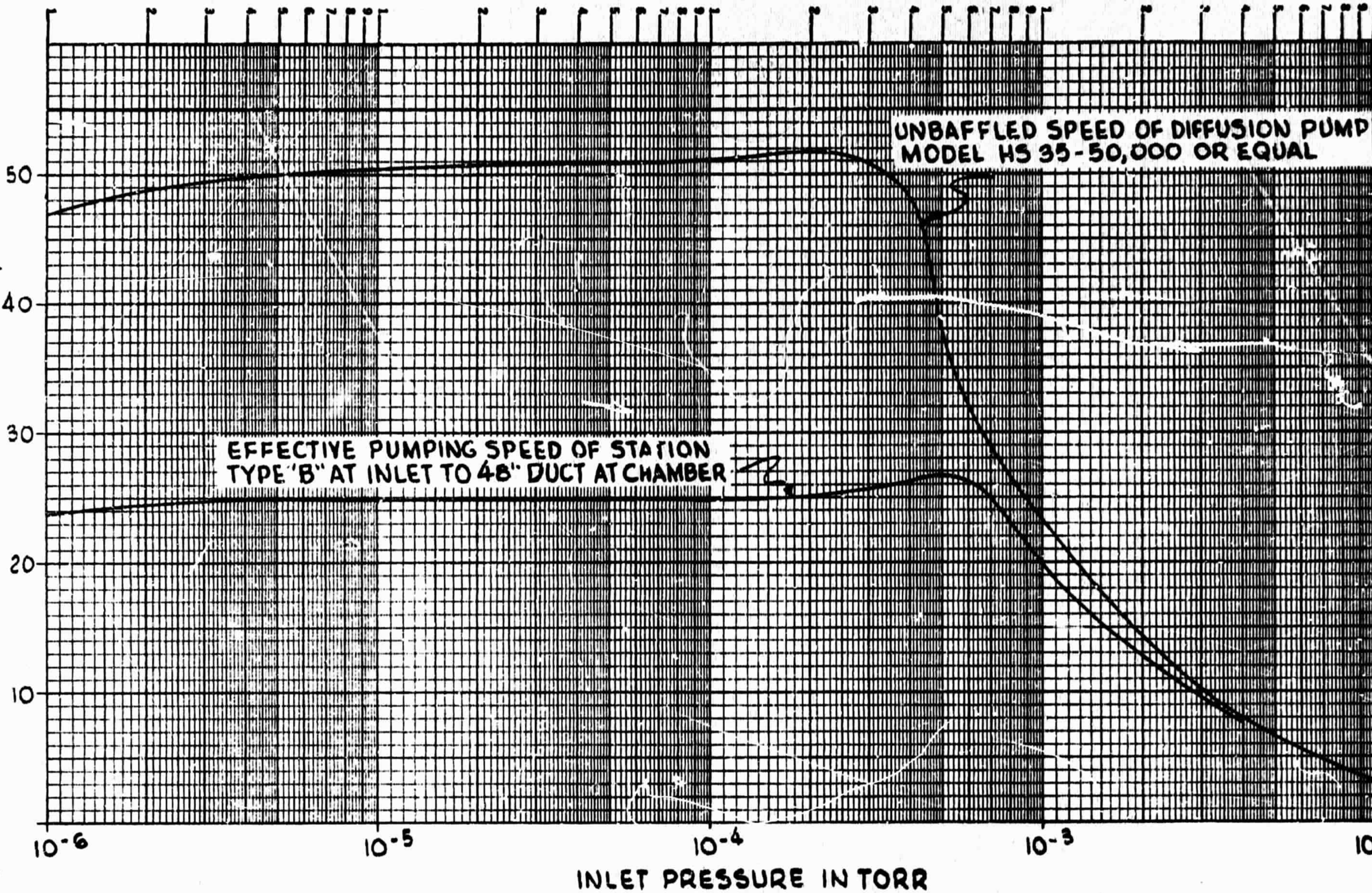
REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MAT'L	APPROVALS	DATE
0								

G-231-E 4-14-60
III



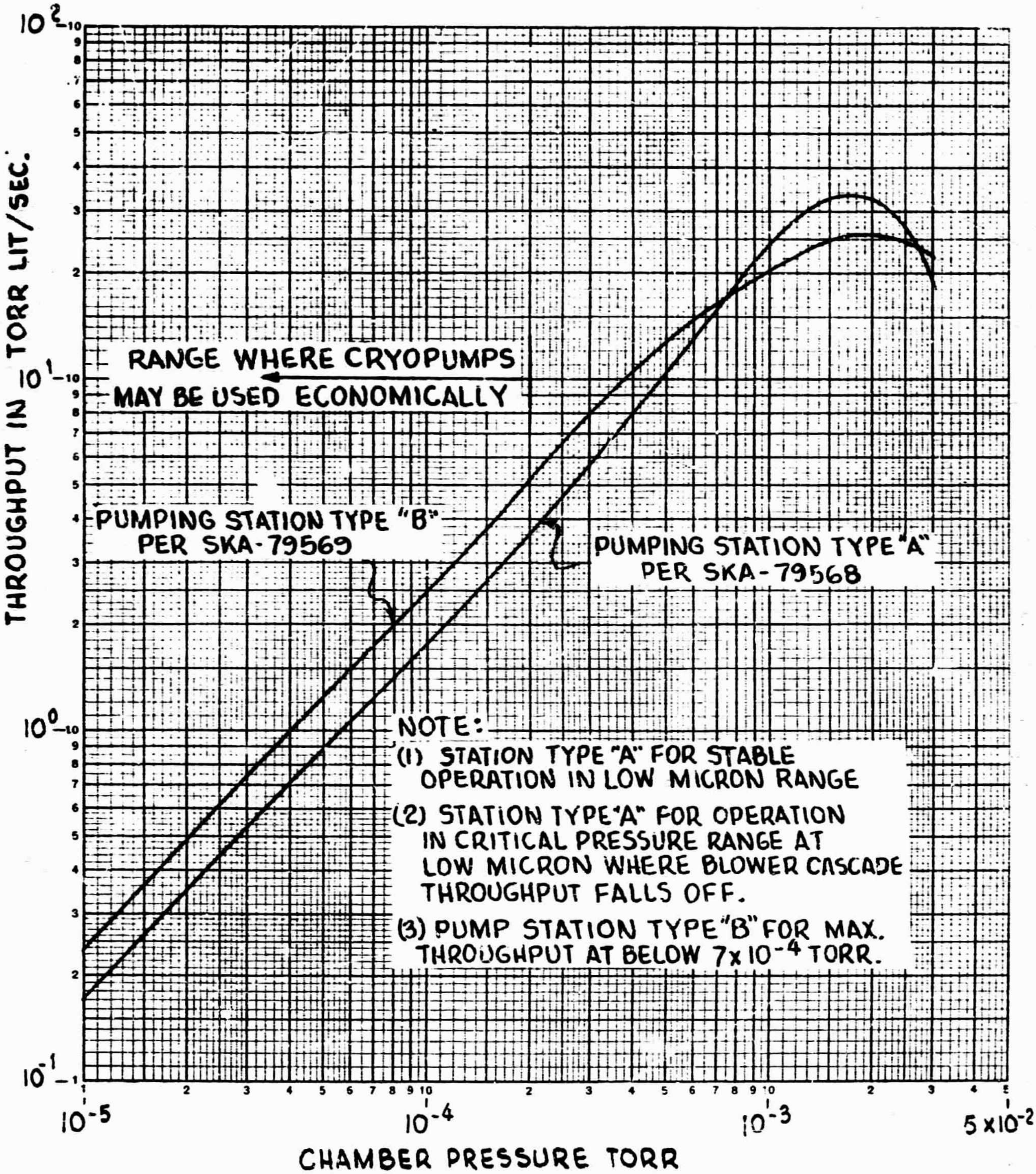
PUMPING STATION TYPE "A"

FIG II-18



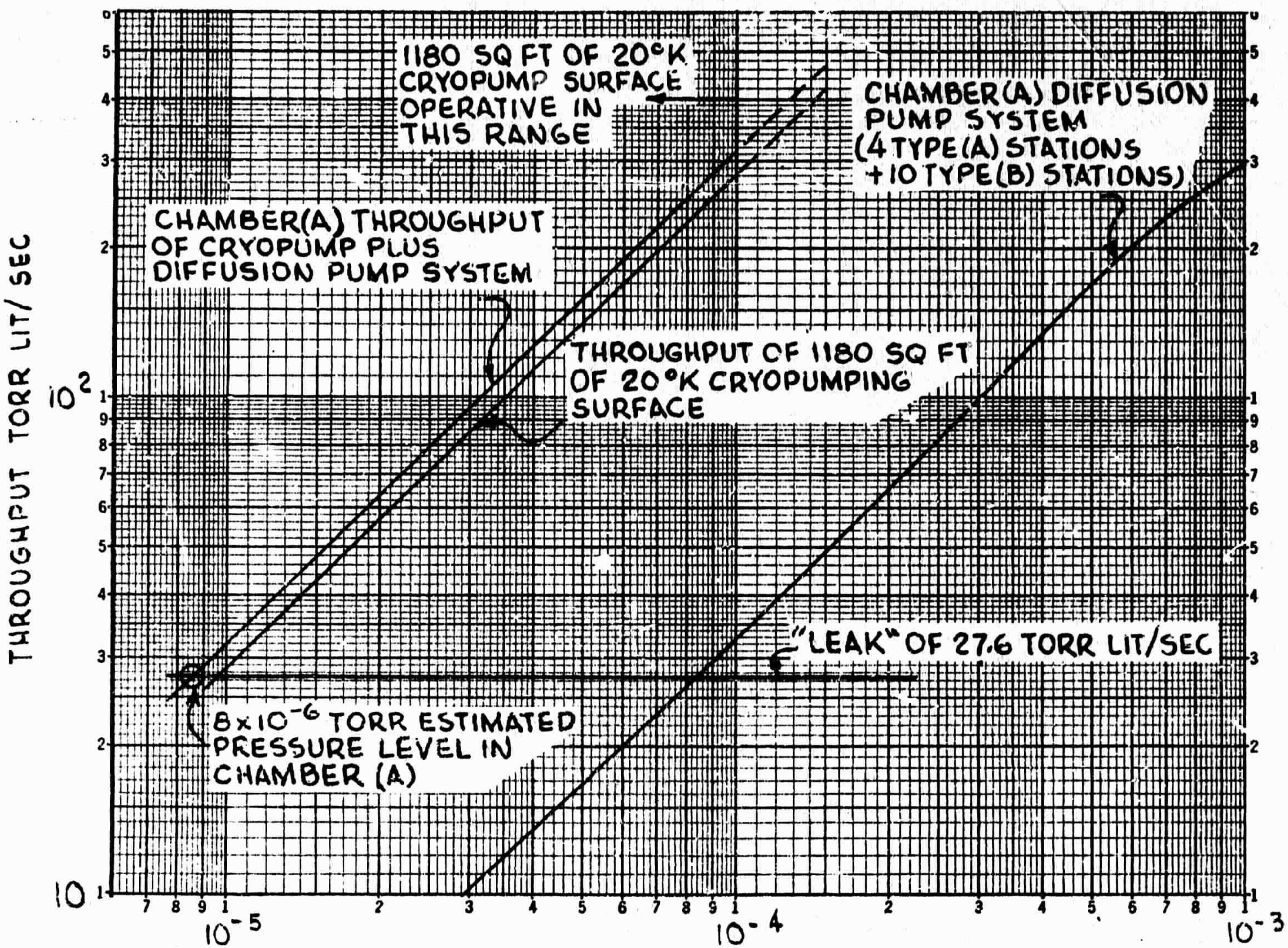
PUMPING STATION TYPE "B"

FIG II-19



THROUGHPUT V. INPUT PRESSURE FOR DIFFUSION PUMP STATIONS TYPE "A" AND TYPE "B"

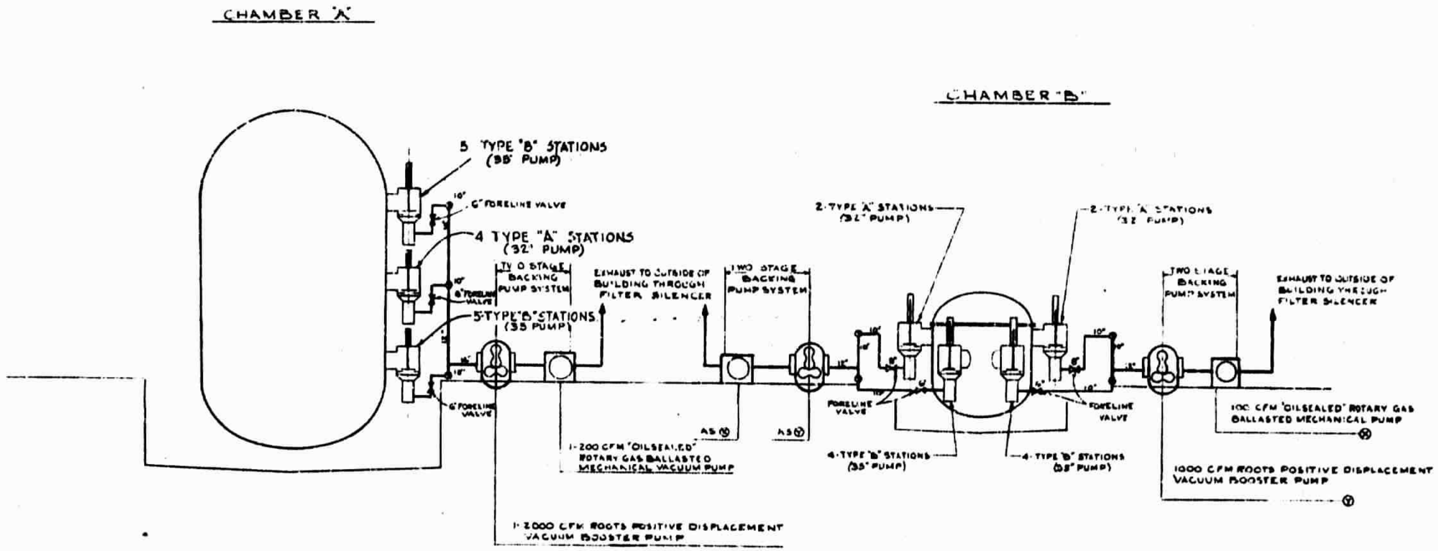
FIG II-20



RECOMMENDED PUMPING SYSTEM
(ATTAINABLE PRESSURE LEVEL CHAMBER A)

FIG. II-21

III



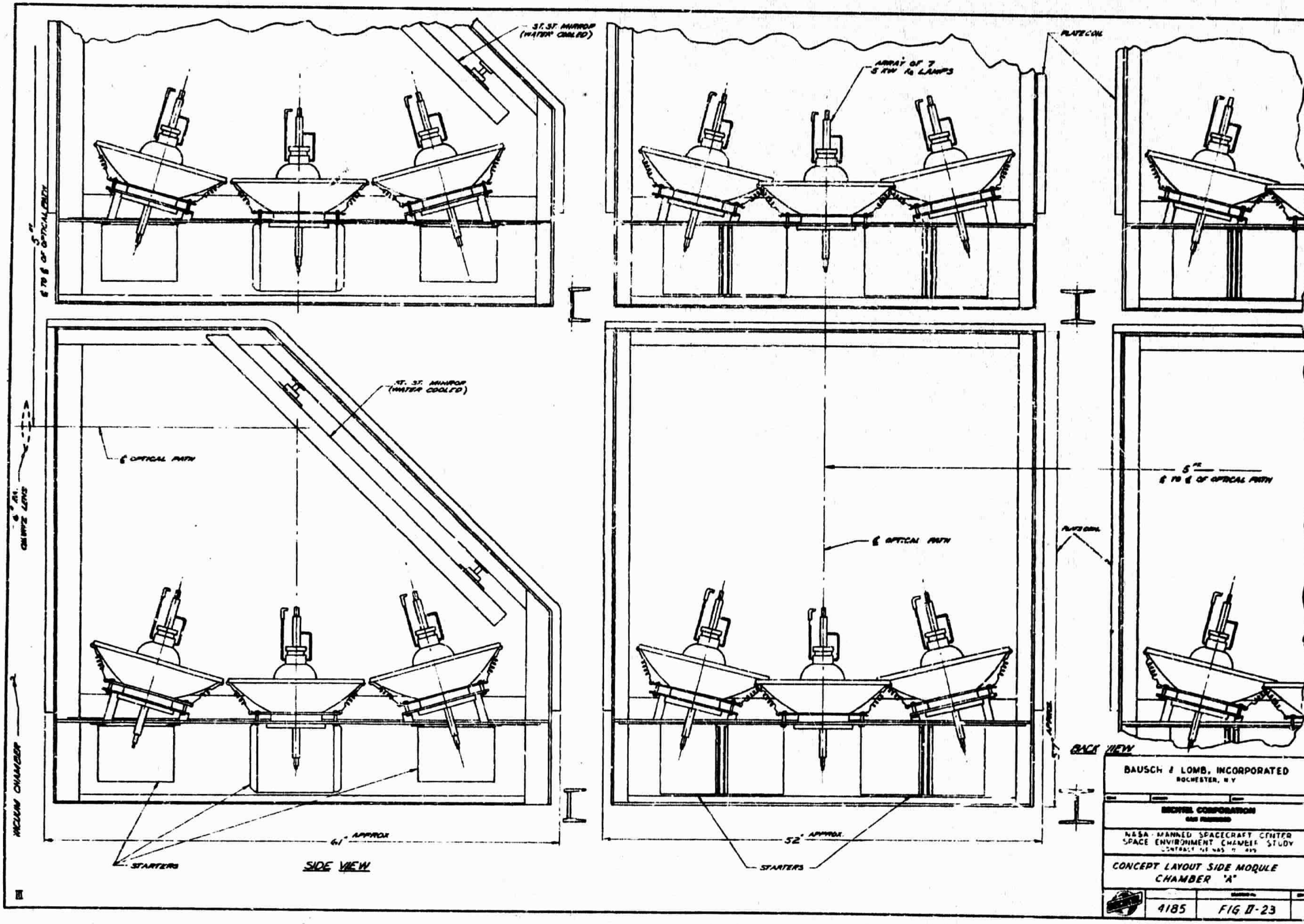
NATIONAL RESEARCH CORP.
CAMBRIDGE, MASS.

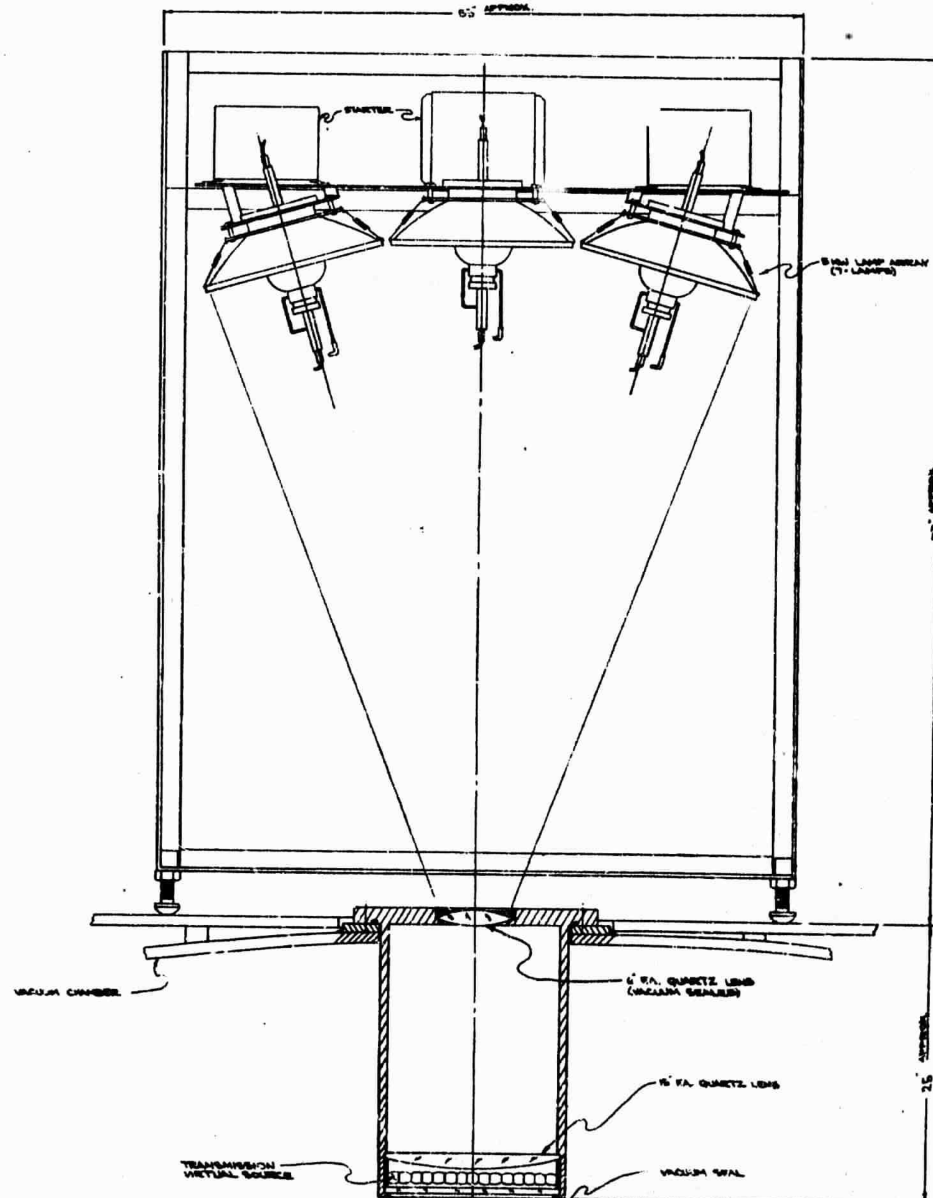
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

SCHEMATC - DIFFUSION PUMP AND BACKING SYSTEMS

4185 FIG II-22

III


ST. ST. MIRROR (WATER COOLED)
ARRAY OF 7 5 KW Xe LAMPS
PLATE COIL
5"
℄ TO ℄ OF OPTICAL PATH
ST. ST. MIRROR (WATER COOLED)
℄ OPTICAL PATH
6" DIA. QUARTZ LENS
VACUUM CHAMBER
℄ OPTICAL PATH
61" APPROX
52" APPROX.
57" APPROX.
STARTERS
SIDE VIEW
STARTERS
BACK VIEW
BAUSCH & LOMB, INCORPORATED
ROCHESTER, N.Y.
BECHTEL CORPORATION
SAN FRANCISCO
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONCEPT LAYOUT SIDE MODULE
CHAMBER "A"
4185
FIG II-23
FIG II-23



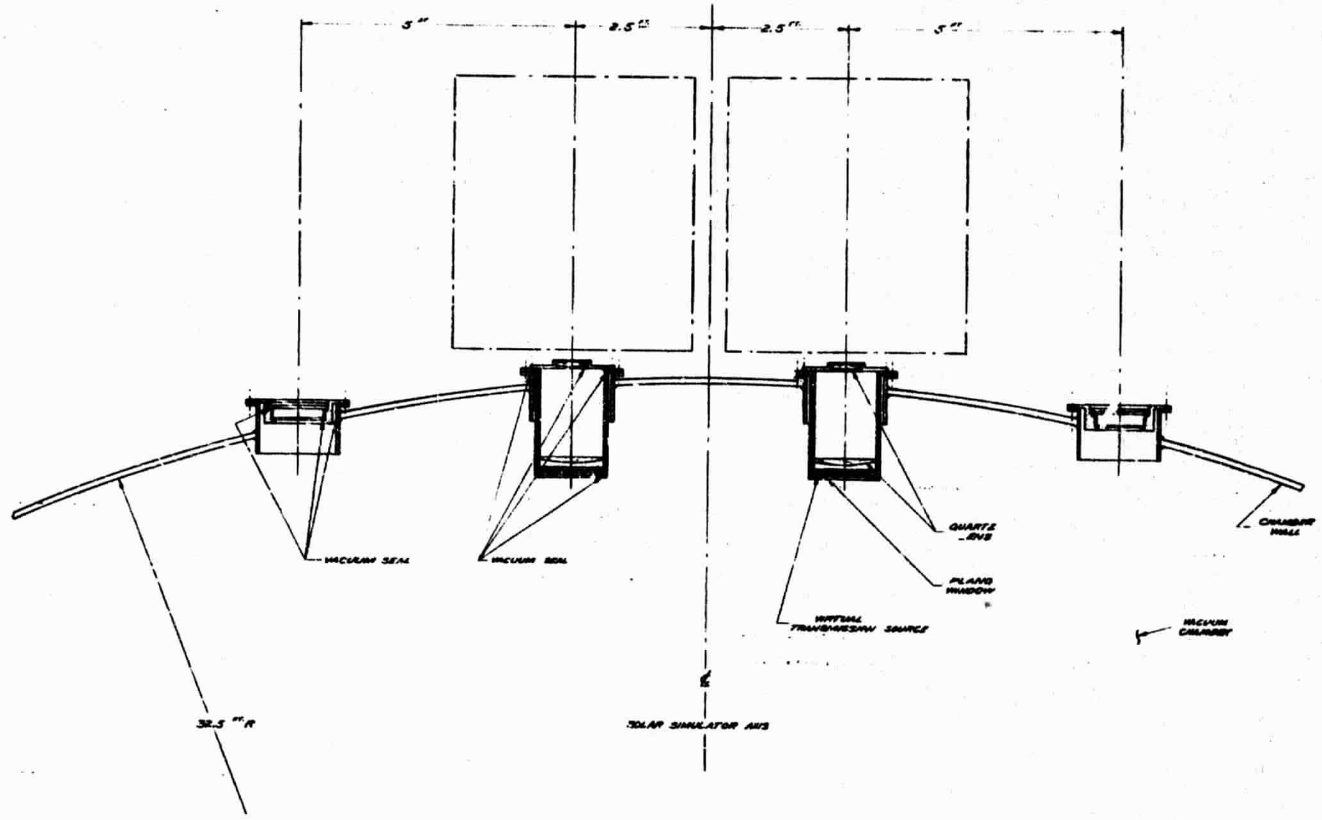
BAUSCH & LOMB, INCORPORATED
ROCHESTER, N.Y.

BECHTEL CORPORATION
SAN FRANCISCO

NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

TOP MODULE - CHAMBER A

4185 FIG. II - 24



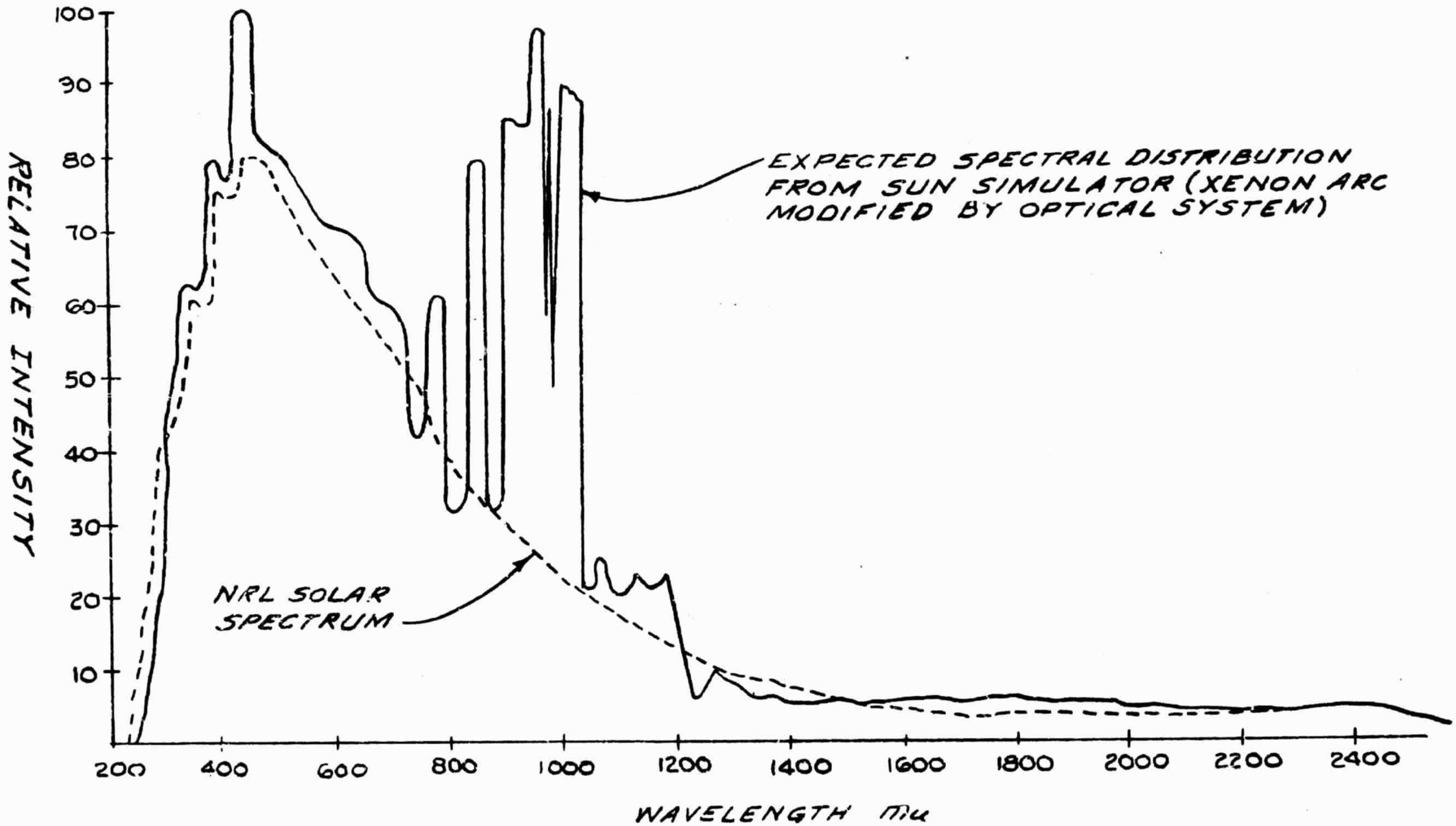
BAUSCH & LOMB, INCORPORATED
ROCHESTER, N.Y.

NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

PLAN SECTION LENS ASSEMBLY
SIDE MODULE CHAMBER "A"

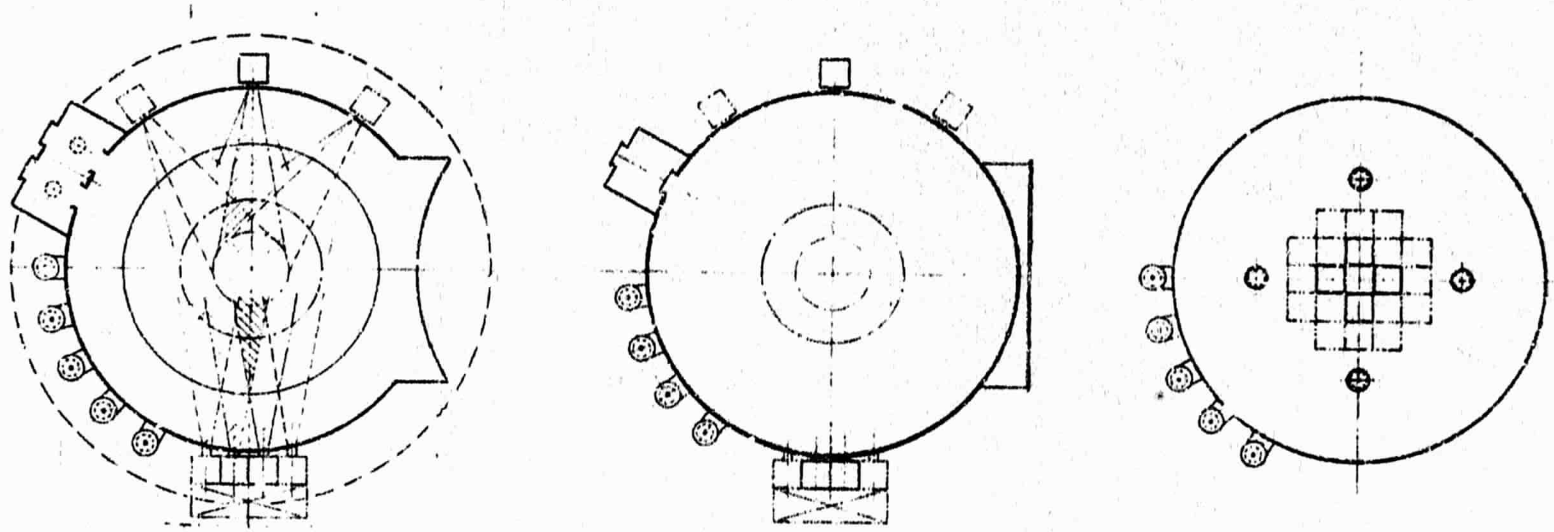
4185 | FIG II-25

III



SPECTRAL DISTRIBUTION OF XENON ARC

FIG. II-26



PLAN OF EL. 27'-0

PLAN OF EL. 86'-0"

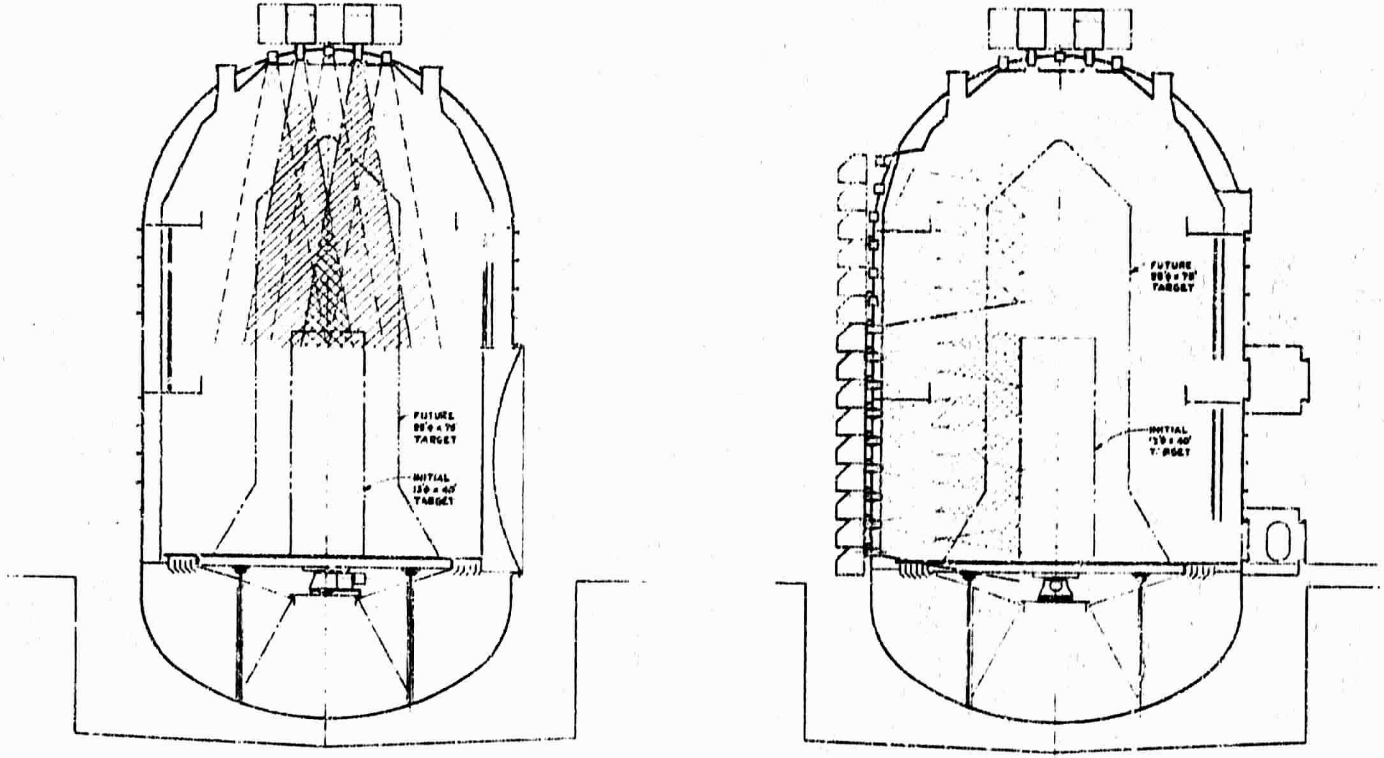
TOP PLAN @ EL. 86'-0"

NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

SOLAR SIMULATION
PLANS
CHAMBER A

4185 FIG. II-27

III



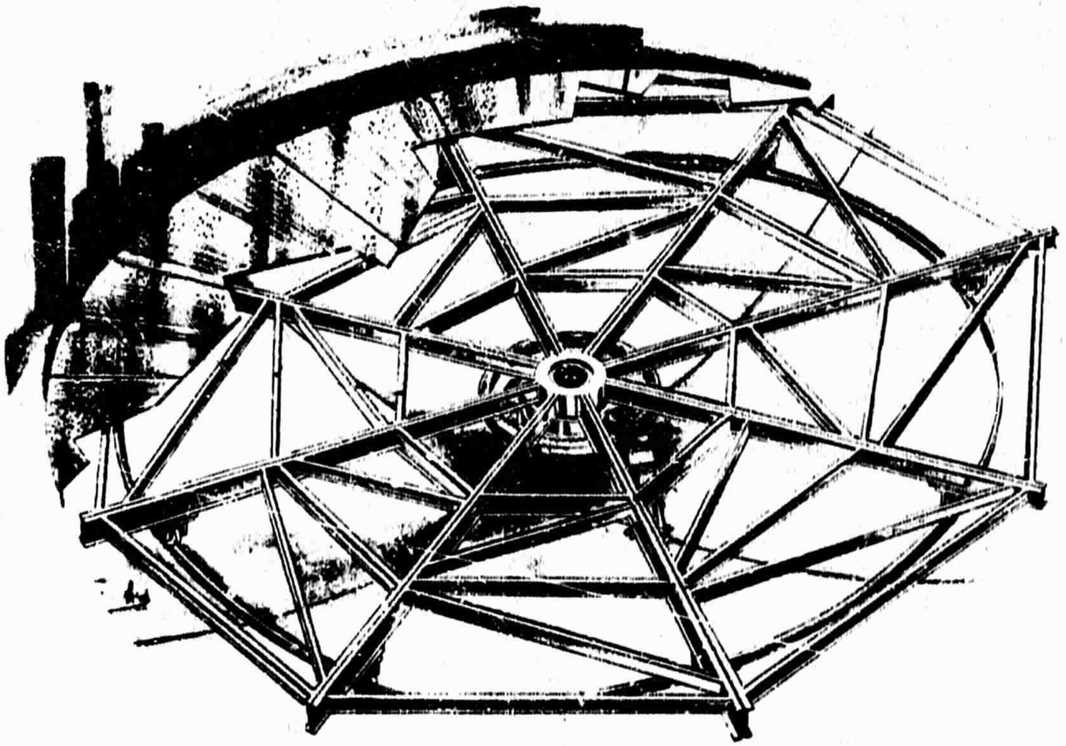
SECTION A-A

SECTION B-B

SOLAR SIMULATION
SECTION A-A & B-B
CHAMBER A

4185

FIG. II-28



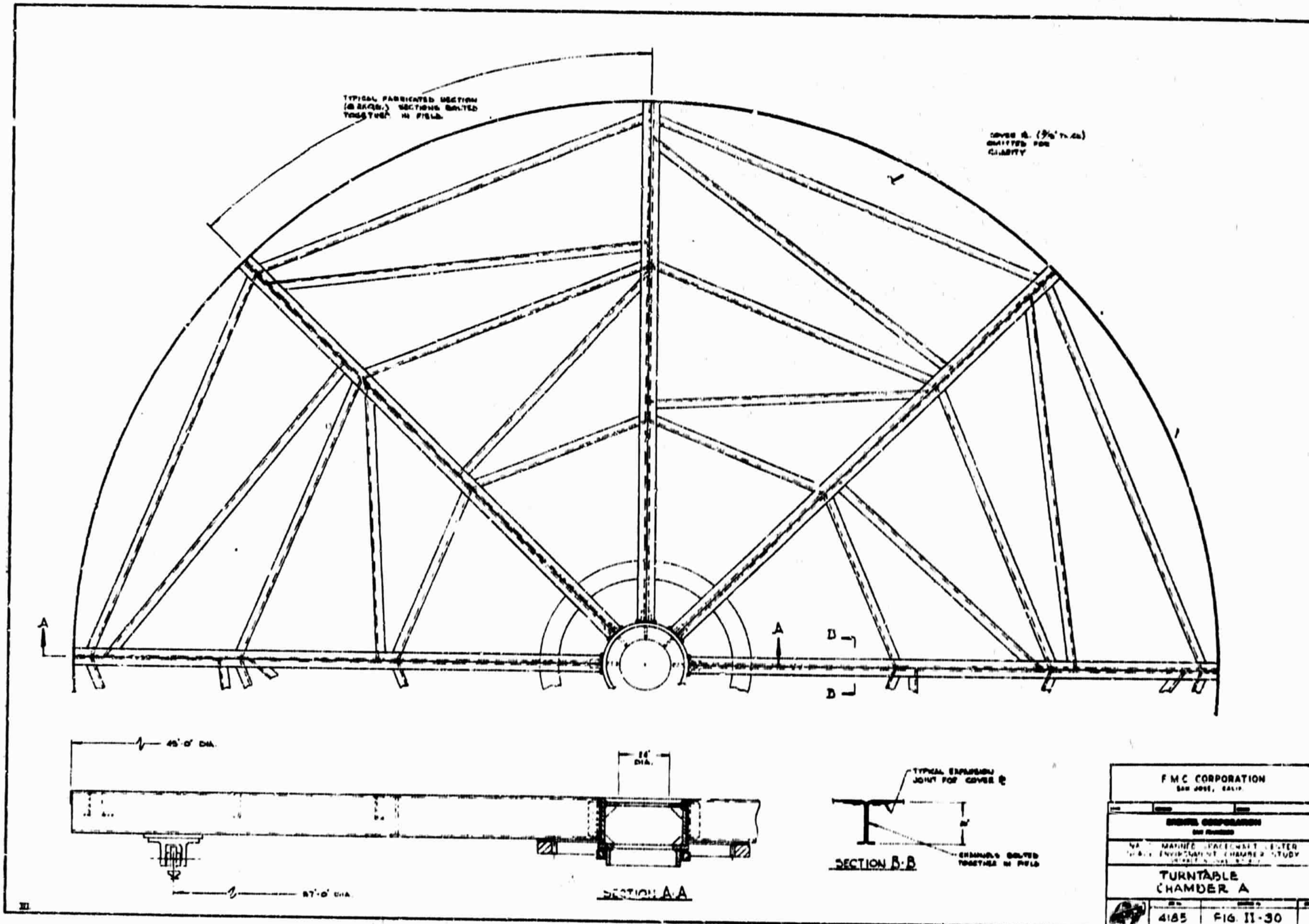
F M C CORPORATION
SAN JOSE, CALIF

NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

PERSPECTIVE
TURNTABLE - CHAMBER A

4185 | FIG. II-29

III



TYPICAL FABRICATED SECTION (6 REQ'D.) SECTIONS BOLTED TOGETHER IN FIELD
SECTION A-A
SECTION B-B
TYPICAL EXPANSION JOINT FOR COVER
CHANNELS BOLTED TOGETHER IN FIELD
F.M.C. CORPORATION
SAN JOSE, CALIF.
TURNTABLE
CHAMBER A
4185
FIG. II-30

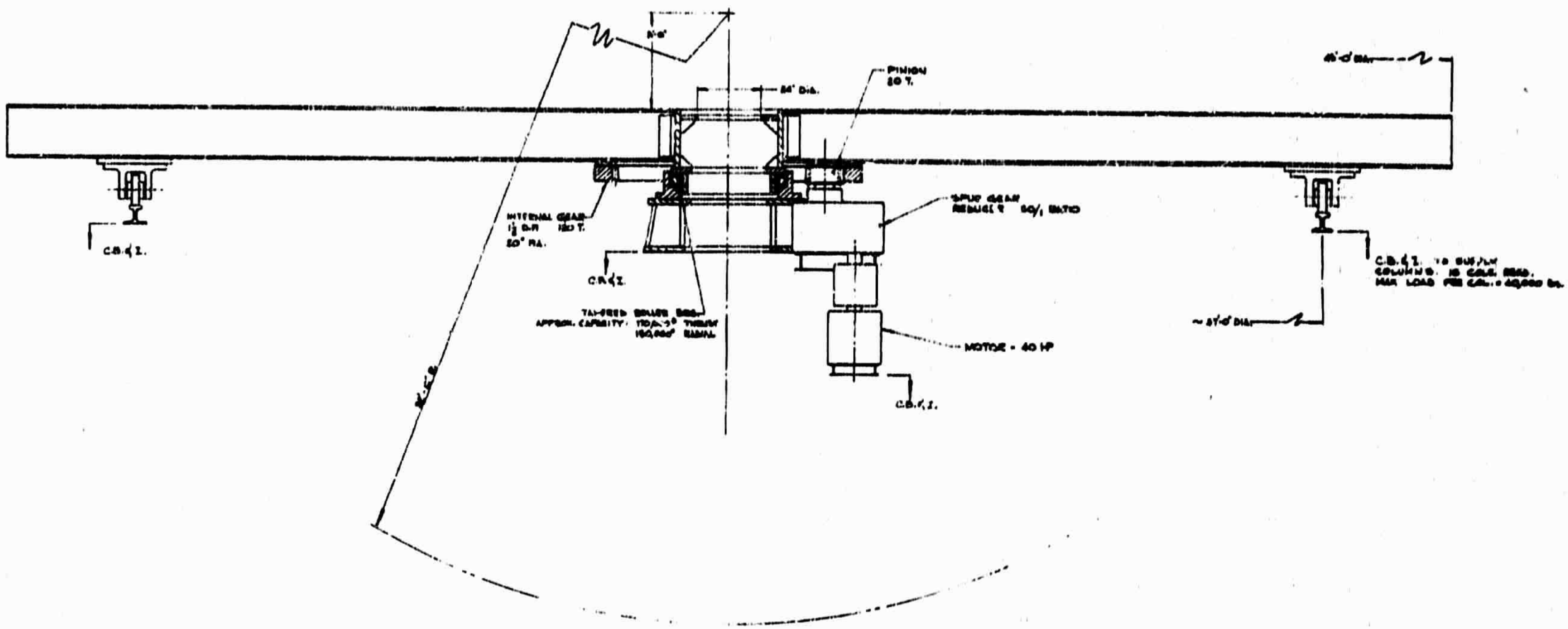


TABLE SPEED: ½ to 1⅔ R.P.M.

FMC CORPORATION
SAN JOSE, CALIF.

SPACE ENVIRONMENT CHAMBER STUDY

TURNTABLE DRIVE
CHAMBER A

4185 | FIG II-31

III

ACCELERATION & DECELERATION (CHAMBER A)

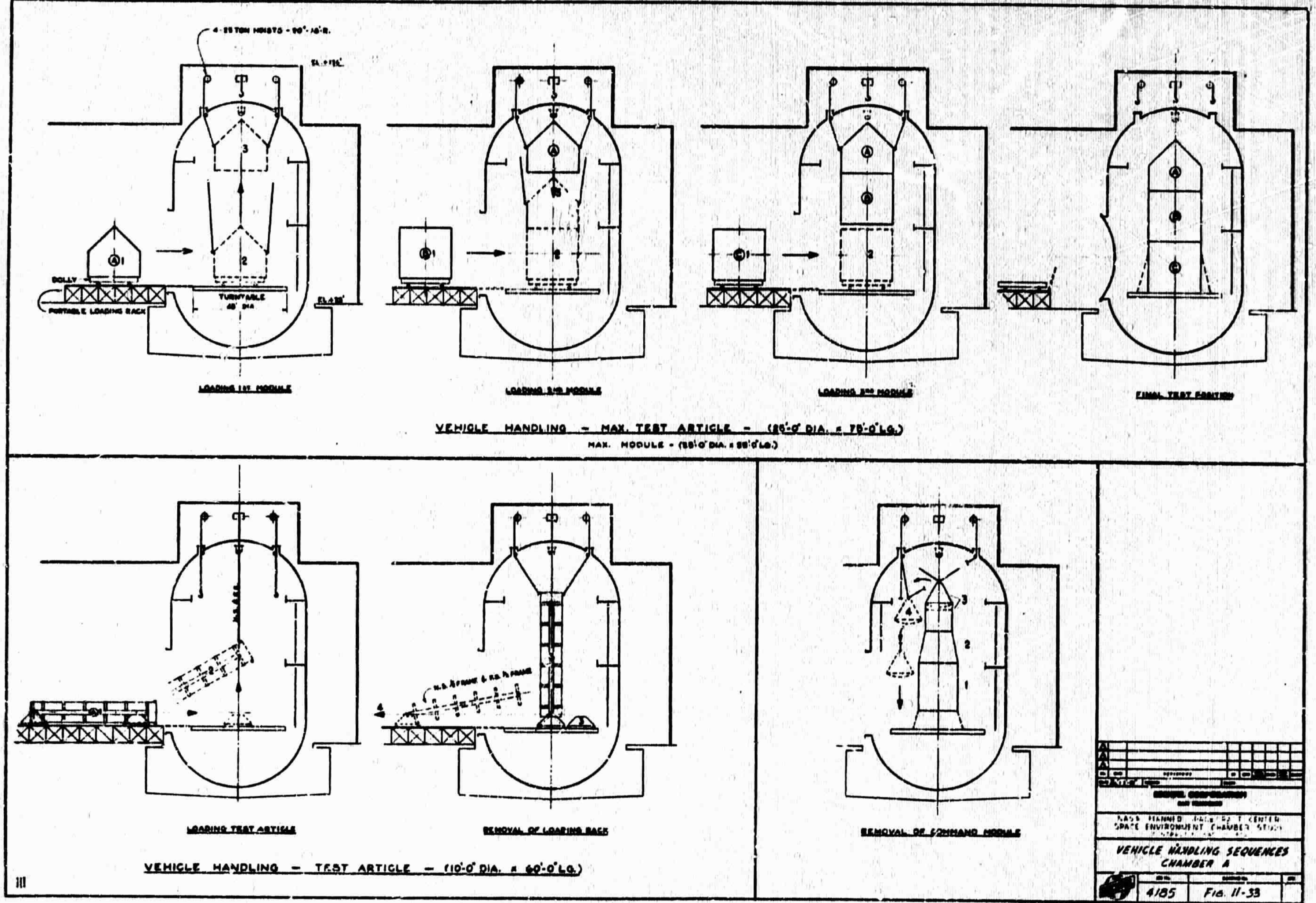
AMOUNT OF ROTATION FOR ACCELERATION AND DECELERATION VERSUS ROTARY TABLE SPEED

CHAMBER A

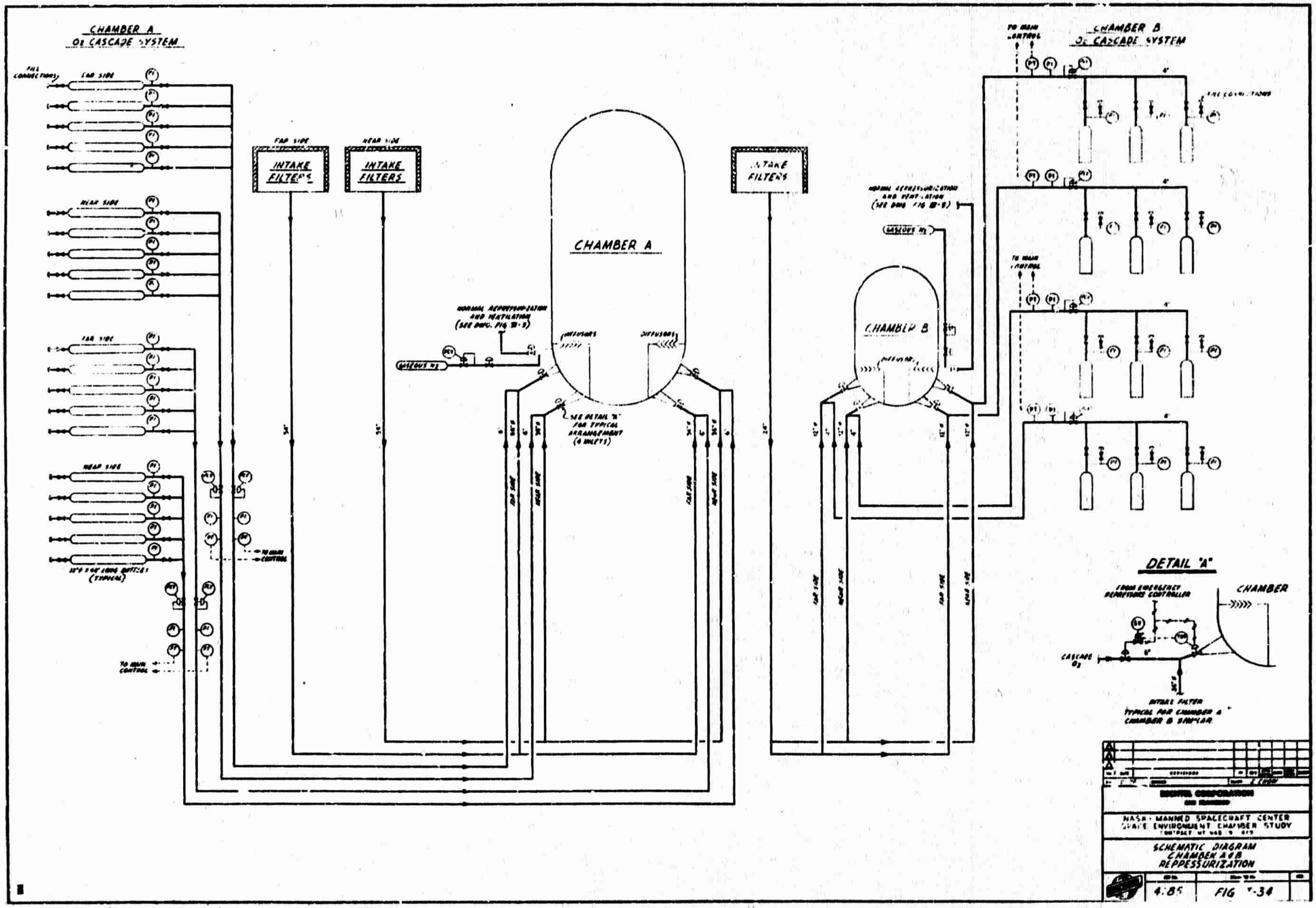
TABLE SPEED (R. P. M.)	DEGREES OF ROTATION REQUIRED FOR ACCELERATION	DEGREES OF ROTATION REQUIRED FOR DECELERATION
1/6	0^o - 48 min.	0^o - 27 min.
1/3	1^o - 36 min.	0^o - 54 min.
1/2	2^o - 24 min.	1^o - 21 min.
2/3	3^o - 12 min.	1^o - 48 min.
5/6	4^o - 0 min.	2^o - 15 min.
1	4^o - 48 min.	2^o - 42 min.
1 1/6	5^o - 36 min.	3^o - 9 min.
1 1/3	6^o - 24 min.	3^o - 36 min.
1 1/2	7^o - 12 min.	4^o - 3 min.
1 3/4	8^o - 0 min.	4^o - 30 min.

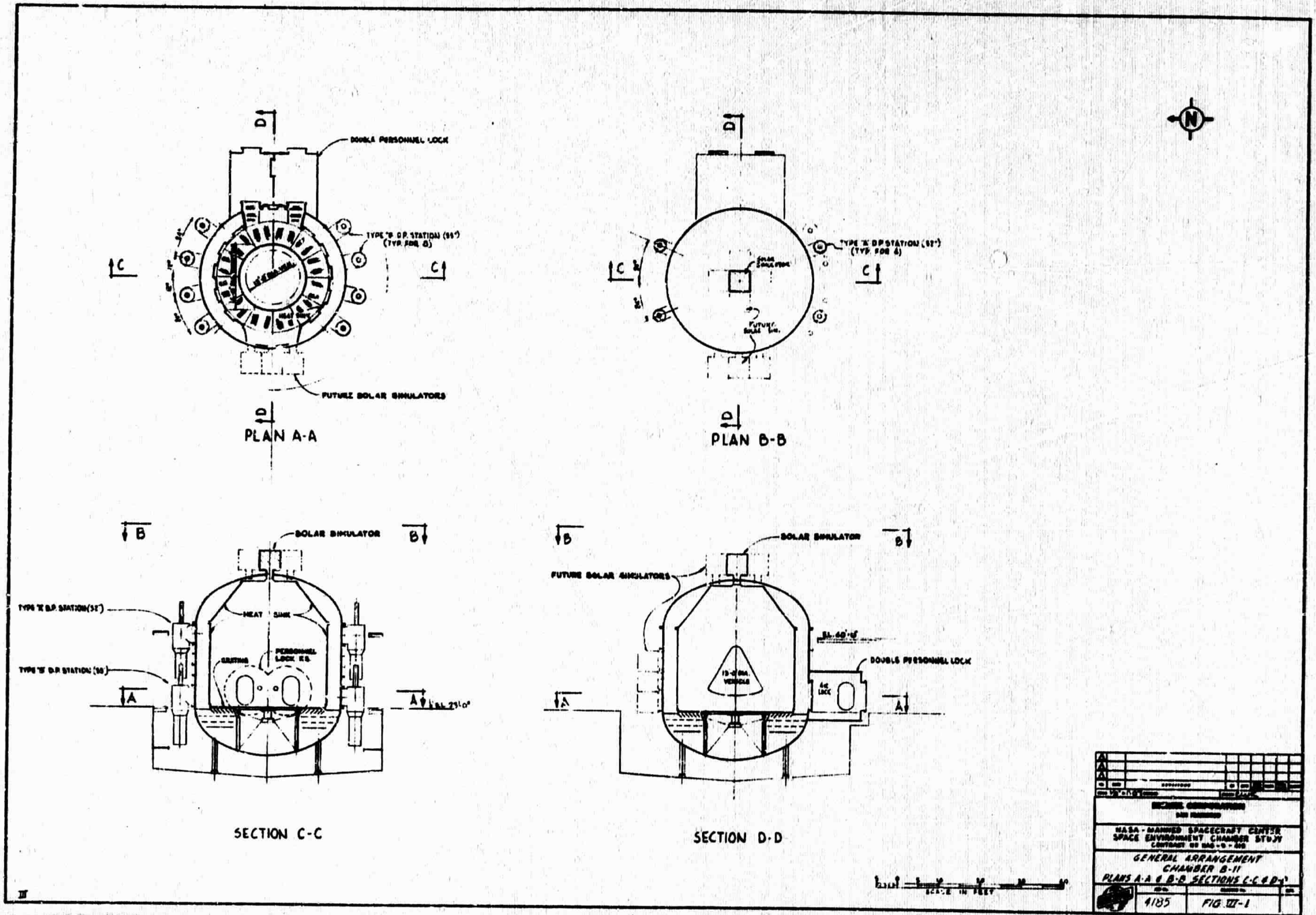
NOTES:

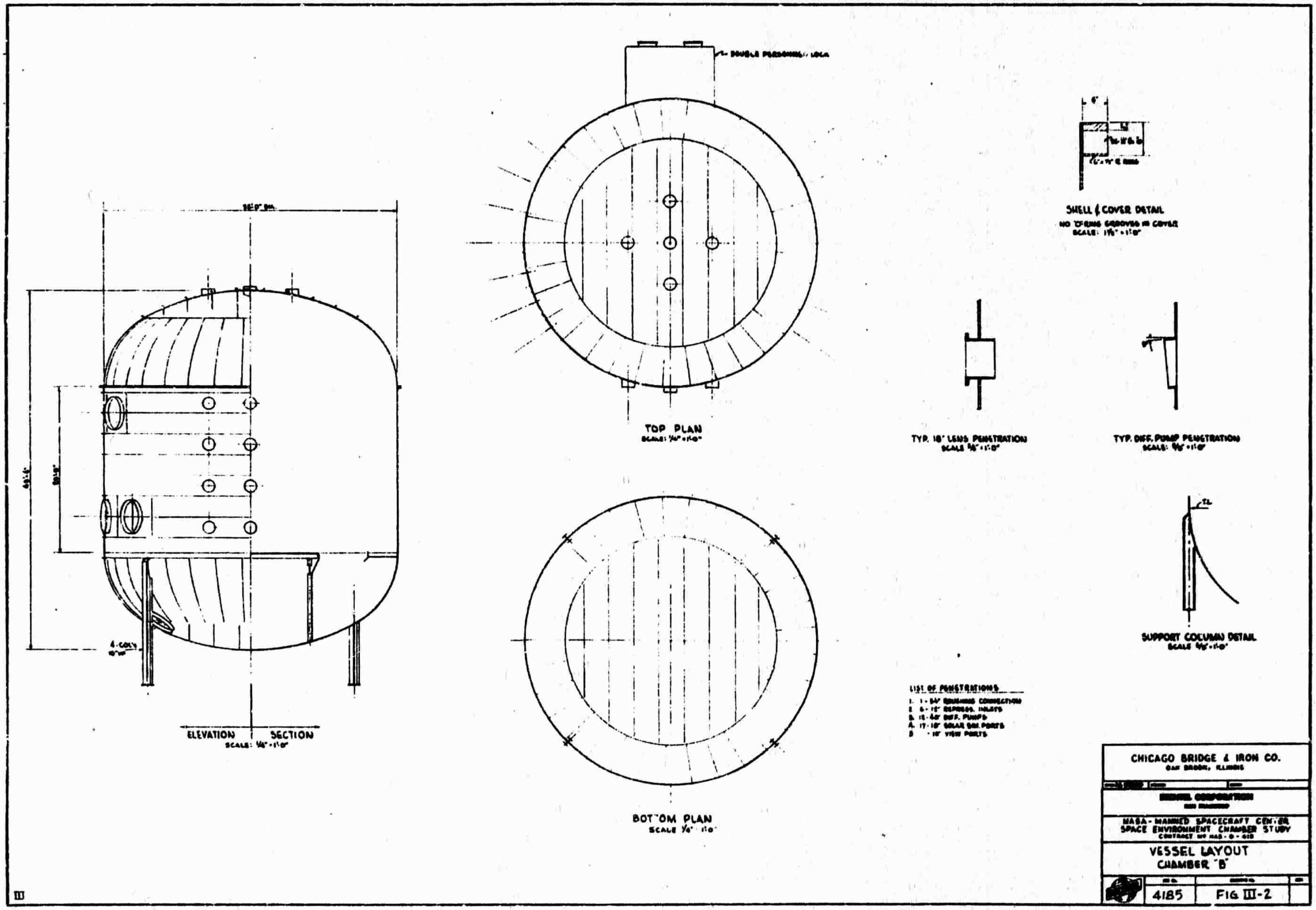
1. 40 HP Drive
2. Total Reduction Motor-Table = 300:1
3. Required Torque to Revolve Table = 6300 ft. lbs
4. Total Available Output Torque @ 100% = 126,000 ft lbs
5. At 100% Motor Torque 126,000-63,000 = 63,000 ft lbs becomes available for acceleration
6. 40% of Motor Braking Torque to Assist in Deceleration of table
7. Total Available Torque to Decelerate Table becomes = 63,000 + 40/100 x 126,000 ≈ 113,000 ft lbs


4 - 25 TON HOISTS
DOLLY
PORTABLE LOADING RACK
TURNTABLE 40' DIA
LOADING 1ST MODULE
LOADING 2ND MODULE
LOADING 3RD MODULE
FINAL TEST POSITION
VEHICLE HANDLING - MAX. TEST ARTICLE - (25'-0" DIA. x 75'-0" LG.)
MAX. MODULE - (25'-0" DIA. x 25'-0" LG.)
LOADING TEST ARTICLE
REMOVAL OF LOADING RACK
REMOVAL OF COMMAND MODULE
VEHICLE HANDLING - TEST ARTICLE - (10'-0" DIA. x 60'-0" LG.)
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
VEHICLE HANDLING SEQUENCES
CHAMBER A
4185
FIG. 11-33

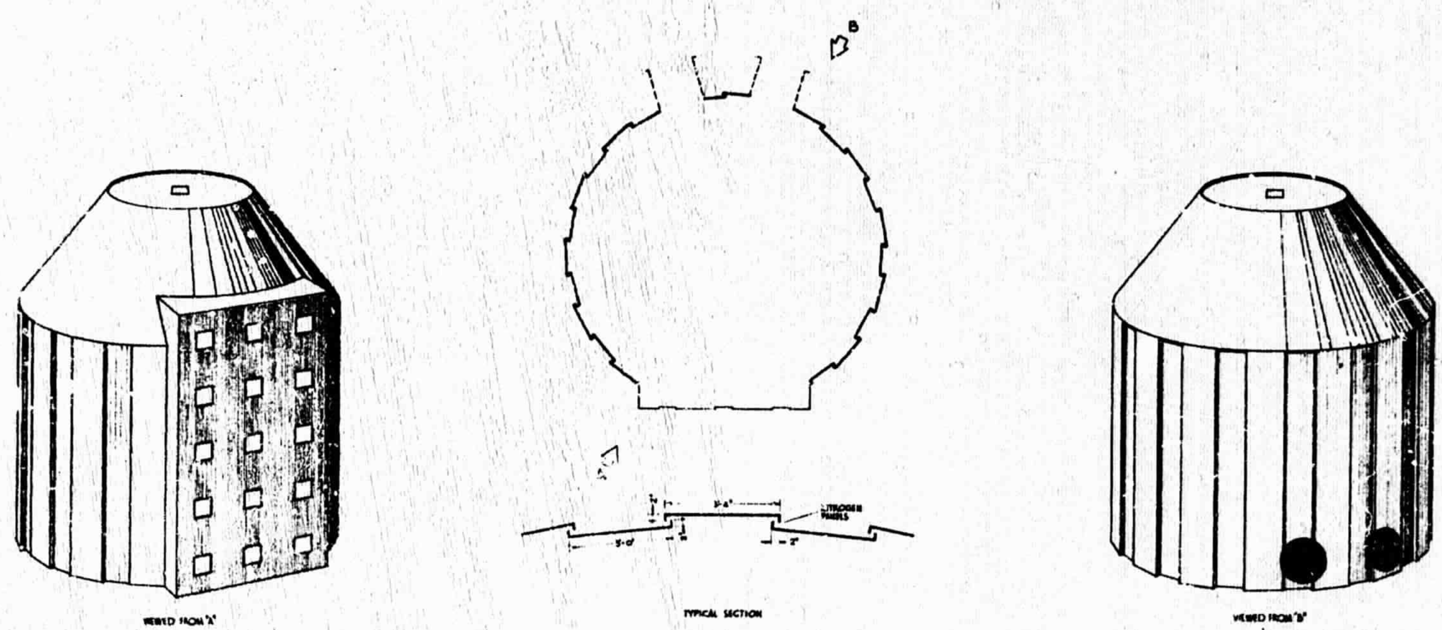
111


CHAMBER A
O2 CASCADE SYSTEM
FILL CONNECTIONS
FAR SIDE
NEAR SIDE
INTAKE FILTERS
CHAMBER A
DIFFUSERS
NORMAL REPRESSURIZATION AND VENTILATION (SEE DWG. FIG B-3)
GASEOUS N2
SEE DETAIL "A" FOR TYPICAL ARRANGEMENT (4 INLETS)
TO MAIN CONTROL
CHAMBER B
O2 CASCADE SYSTEM
CHAMBER B
DETAIL "A"
FROM EMERGENCY REPRESSURE CONTROLLER
CHAMBER
CASCADE O2
INTAKE FILTER
TYPICAL FOR CHAMBER A CHAMBER B SIMILAR
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
SCHEMATIC DIAGRAM
CHAMBER A & B
REPRESSURIZATION
4:85
FIG -34


DOUBLE PERSONNEL LOCK
TYPE "B" D.P. STATION (36")
(TYP. FOR 8)
FUTURE SOLAR SIMULATORS
PLAN A-A
TYPE "A" D.P. STATION (32")
(TYP. FOR 4)
PLAN B-B
SOLAR SIMULATOR
HEAT SINK
GRATING
PERSONNEL LOCK
TYPE "A" D.P. STATION (32")
TYPE "B" D.P. STATION (36")
SECTION C-C
FUTURE SOLAR SIMULATORS
DOUBLE PERSONNEL LOCK
SECTION D-D
SCALE IN FEET
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
GENERAL ARRANGEMENT
CHAMBER B-11
PLANS A-A & B-B SECTIONS C-C & D-D
4185
FIG. III-1
III


DOUBLE PERSONNEL LOCK
ELEVATION SECTION
TOP PLAN
BOTTOM PLAN
SHELL & COVER DETAIL
TYP. 18" LENS PENETRATION
TYP. DIFF. PUMP PENETRATION
SUPPORT COLUMN DETAIL
LIST OF PENETRATIONS
CHICAGO BRIDGE & IRON CO.
OAK BROOK, ILLINOIS
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
VESSEL LAYOUT
CHAMBER "B"
4185
FIG III-2

III



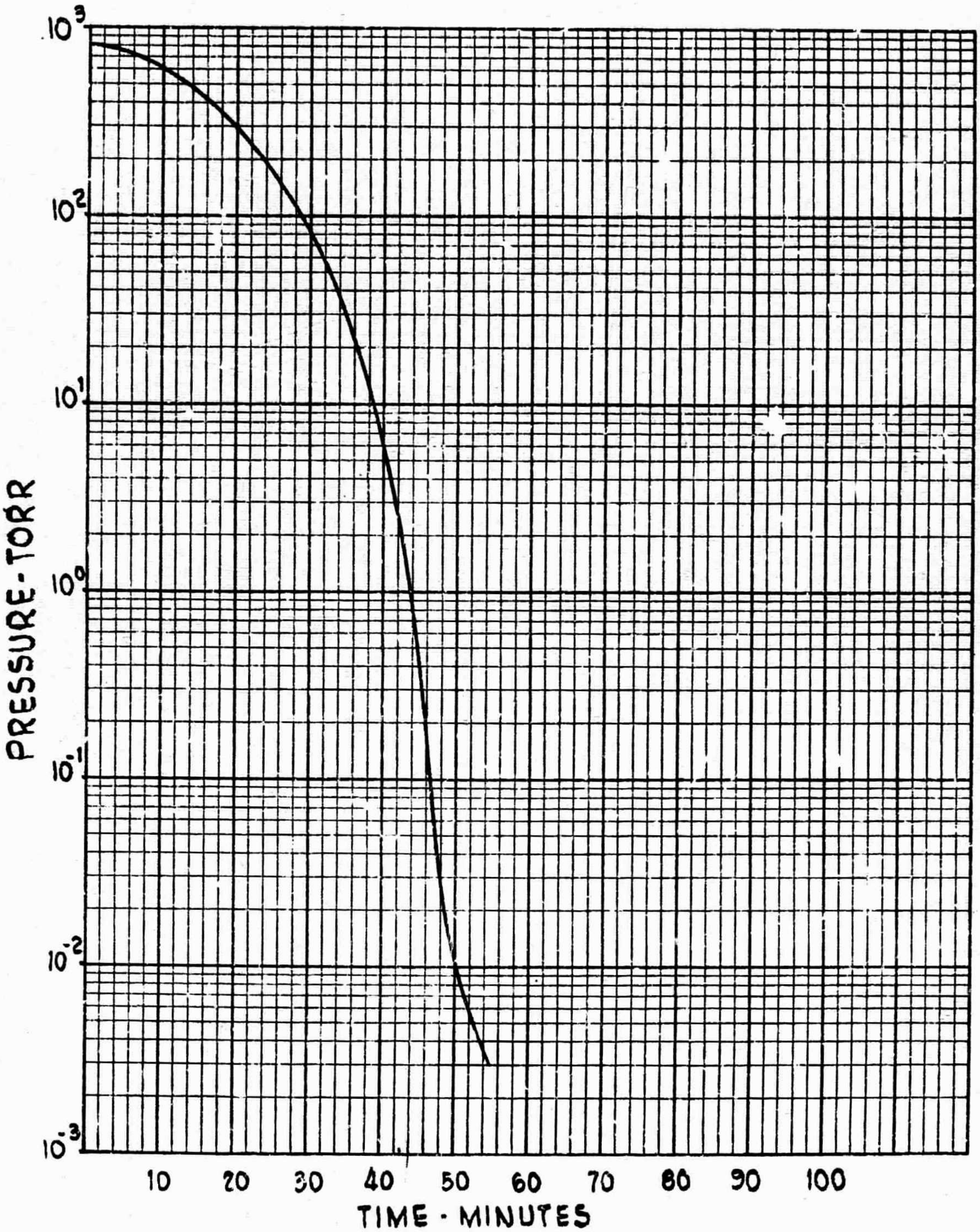
AIR PRODUCTS AND CHEMICALS, INC.
ALLENTOWN, PENN.

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

CHAMBER B - ISOMETRIC CRYOGENIC PANEL ARRGT

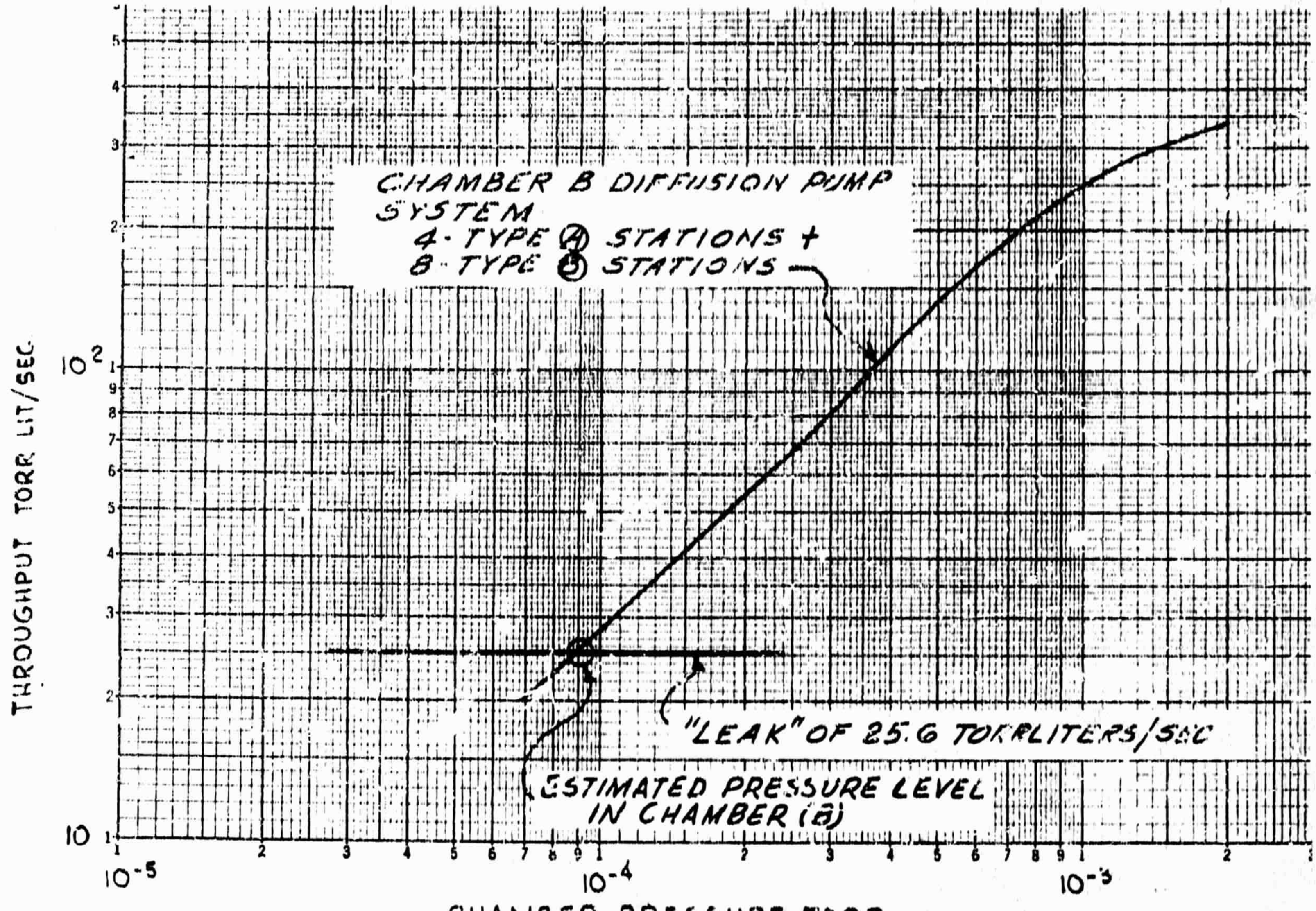
4185 | FIG. III-5

III



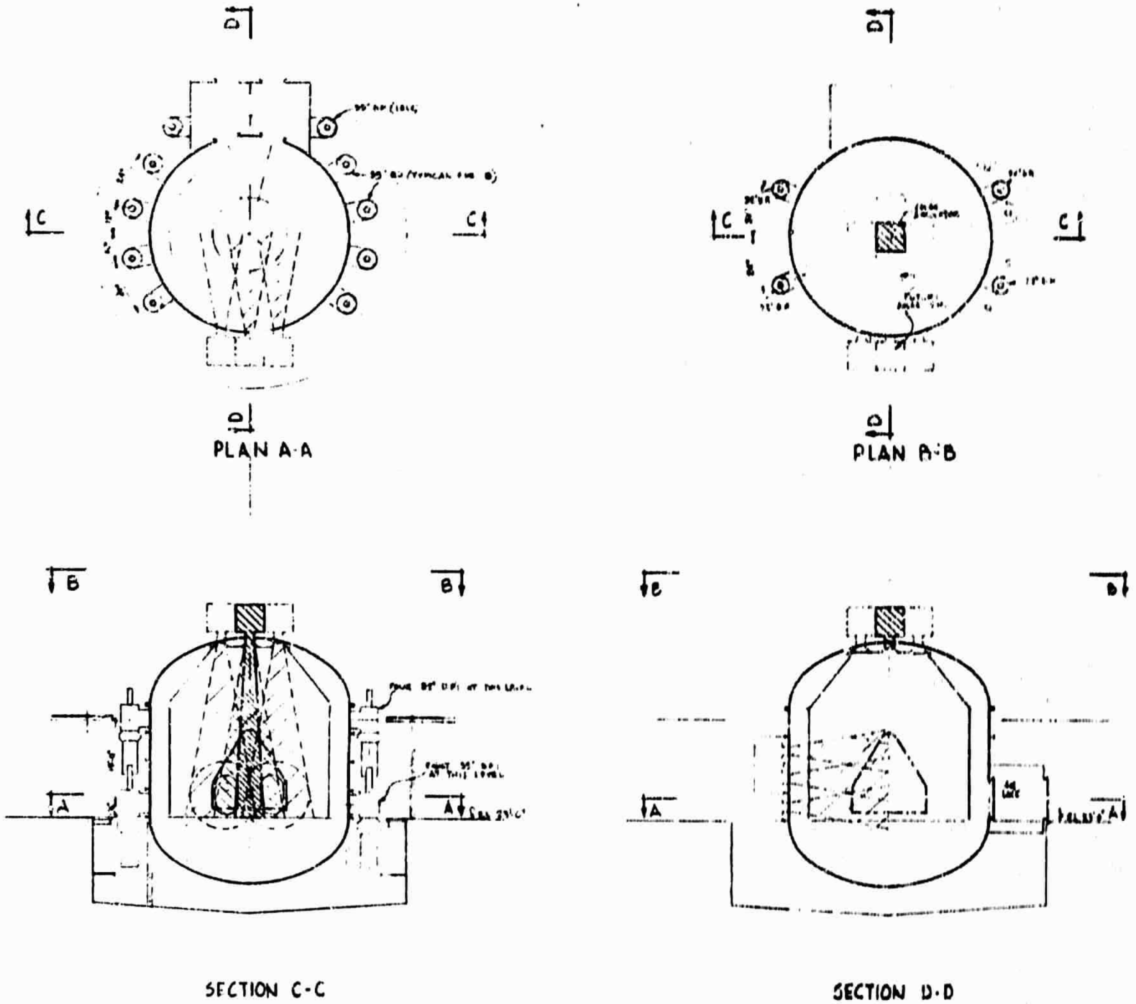
CHAMBER B-11 ROUGHING PUMP DOWN CURVE

FIG. III-4



RECOMMENDED PUMPING SYSTEM
(ATTAINABLE PRESSURE LEVEL CHAMBER B)

FIG. III-5

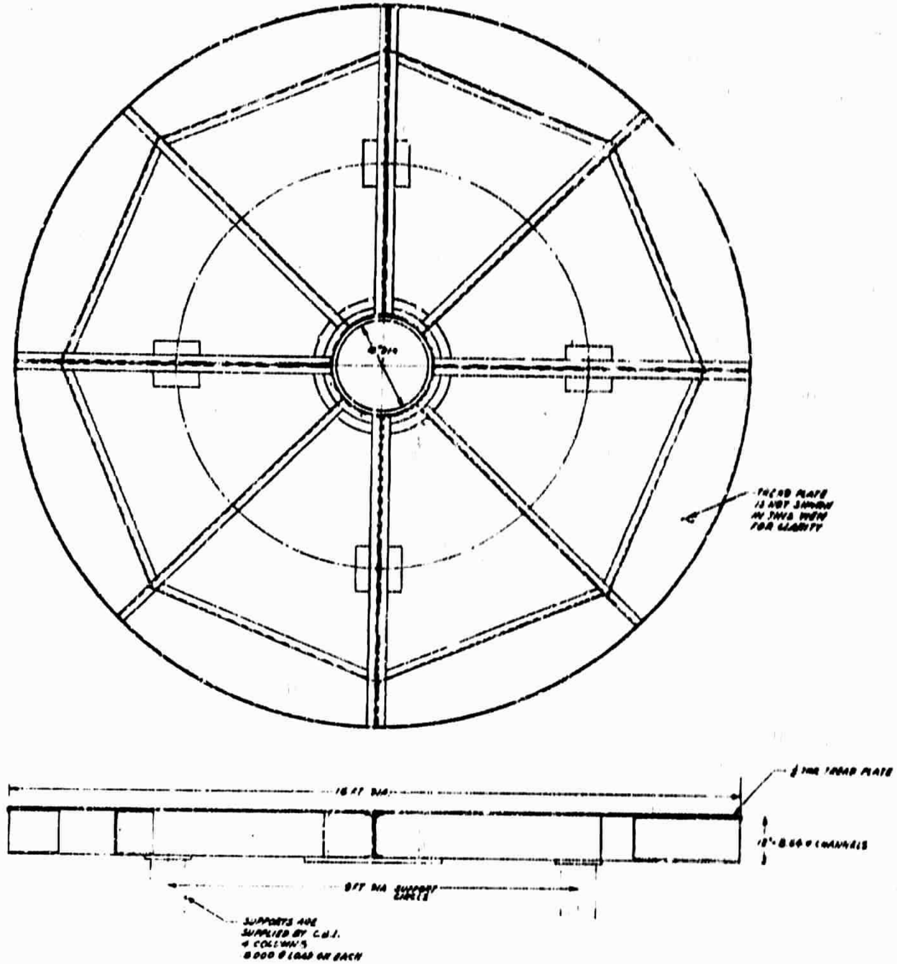


SOLAR SIMULATION
PLANS & SECTIONS
CHAMBER-B

SPACE ENVIRONMENT CHAMBER STUDY

FIG. III-6

III



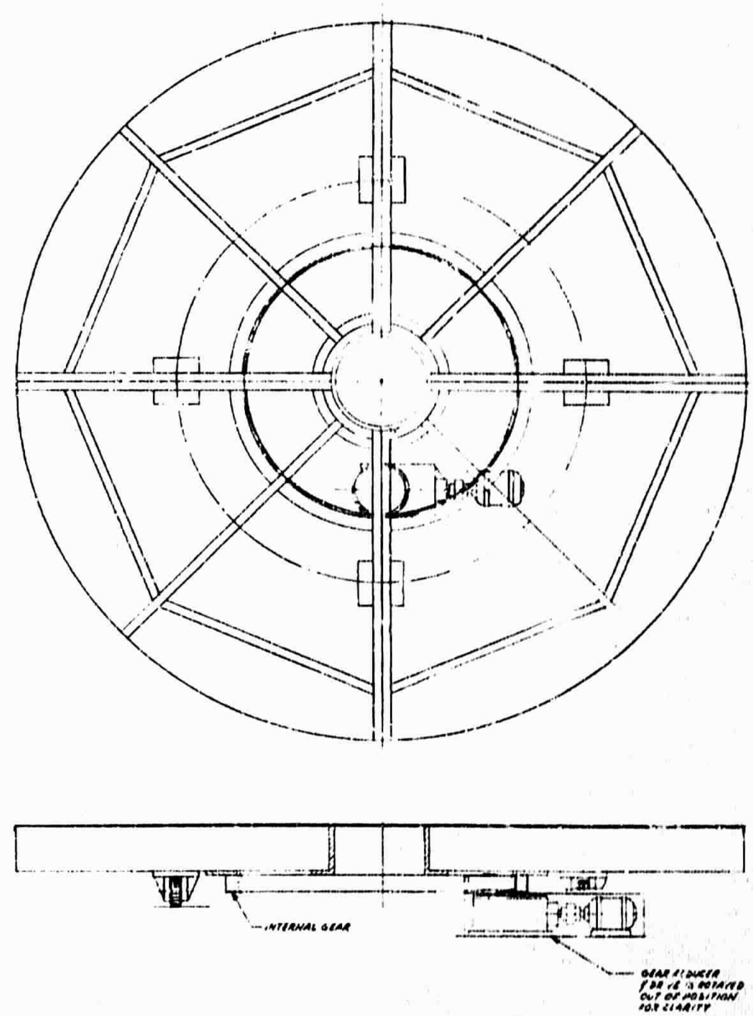
F M C CORPORATION
SAN JOSE, CALIF.

BECHTEL CORPORATION
SAN FRANCISCO

N.A.S.A. MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

TABLE.
CHAMBER B

4185 FIG III-7



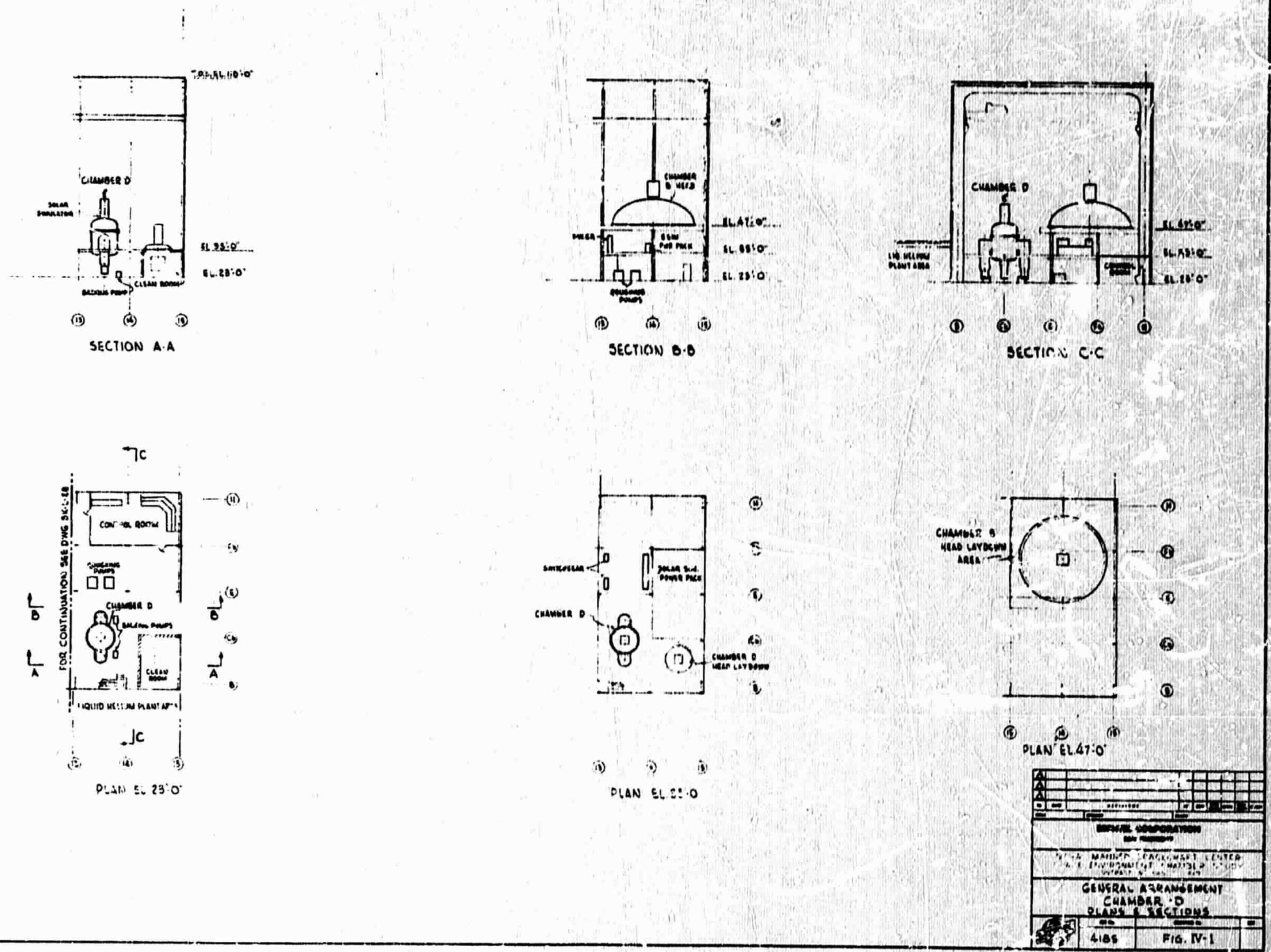
FMC CORPORATION
SAN JOSE, CALIF

SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

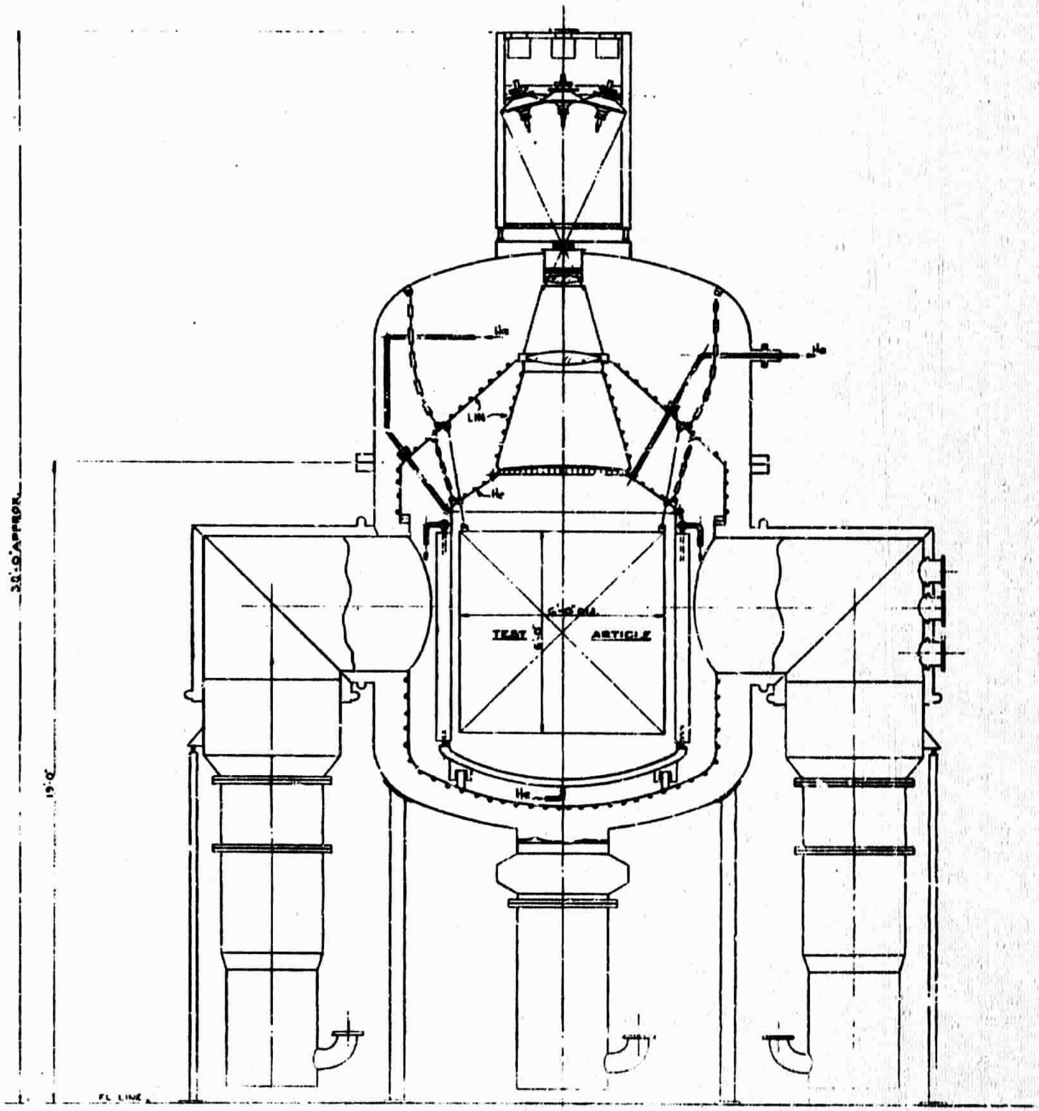
PROVISION FOR TABLE POTATION
CHAMBER B

4185 | FIG III-8

III

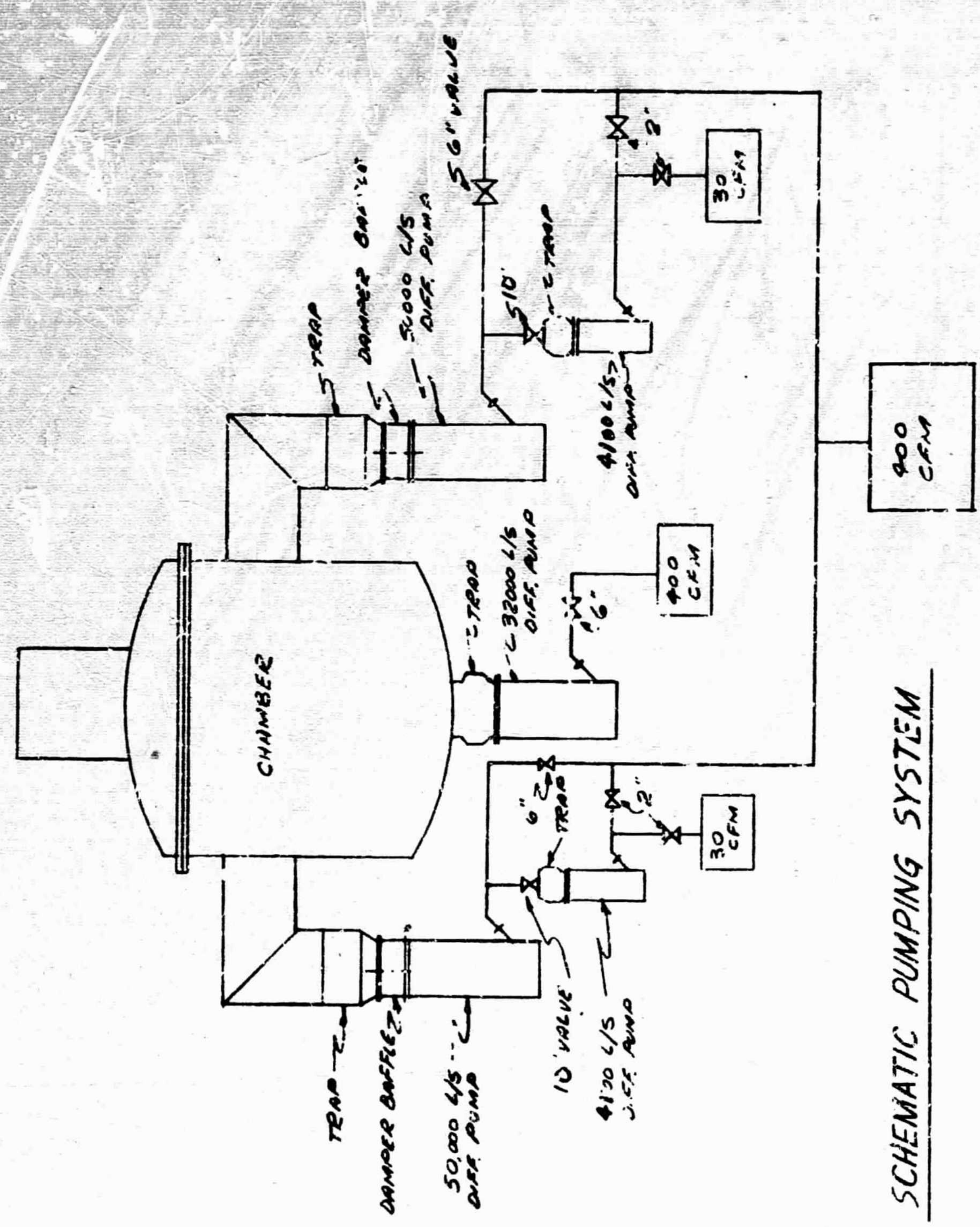

SECTION A-A
CHAMBER D
SOLAR SIMULATOR
CLEAN ROOM
BACKING PUMP
EL 23'-0"
SECTION B-B
CHAMBER D HEAD
EL 47'-0"
EL 23'-0"
SECTION C-C
CHAMBER D
EL 23'-0"
PLAN EL 23'-0"
CONTROL ROOM
CHAMBER D
BACKING PUMPS
CLEAN ROOM
LIQUID HELIUM PLANT AREA
FOR CONTINUATION SEE DWG SK-L-28
PLAN EL 33'-0"
SWITCHGEAR
CHAMBER D
CHAMBER D HEAD LAYDOWN
PLAN EL 47'-0"
CHAMBER D HEAD LAYDOWN AREA
GENERAL ARRANGEMENT
CHAMBER D
PLANS & SECTIONS
4185
FIG. IV-1

III



CHAMBER D - SECTION
GENERAL ARRANGEMENT

4165 FIG. IV-2

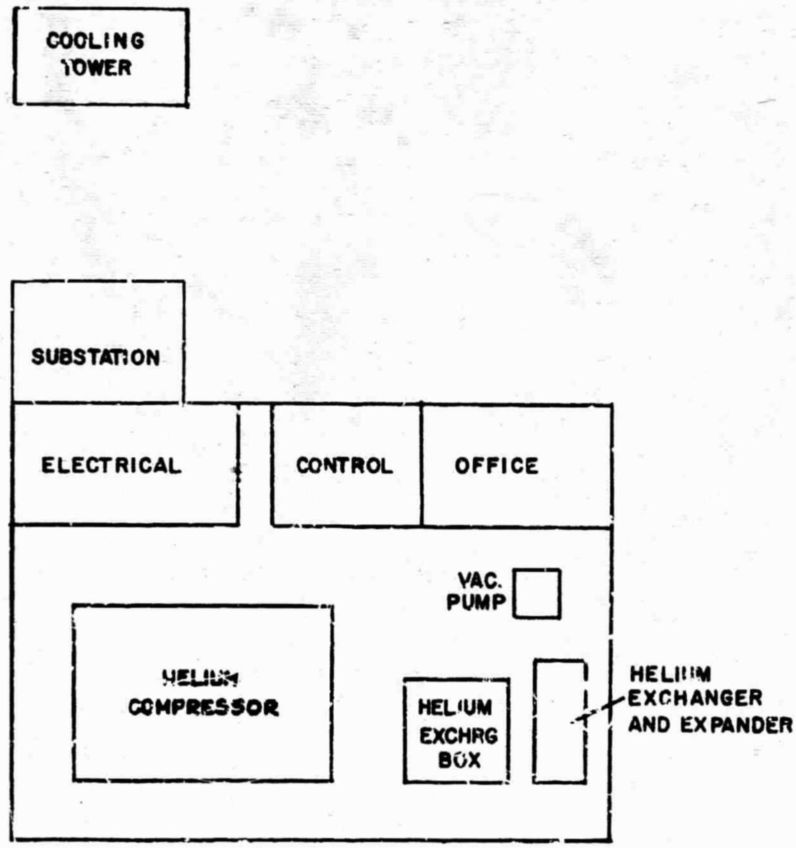


SCHEMATIC PUMPING SYSTEM

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
0								

BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT Nº NAS-9-419	JOB No 4185	REV.
	SCHEMATIC PUMPING SYSTEM	FIG IV-3	

G-231-E 4-14-58



16.10

SCALE 1" = 20'

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MATL	APPROVALS	DATE
0								

BECHTEL CORPORATION
POWER AND INDUSTRIAL DIVISION

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT No NAS - 9 - 419

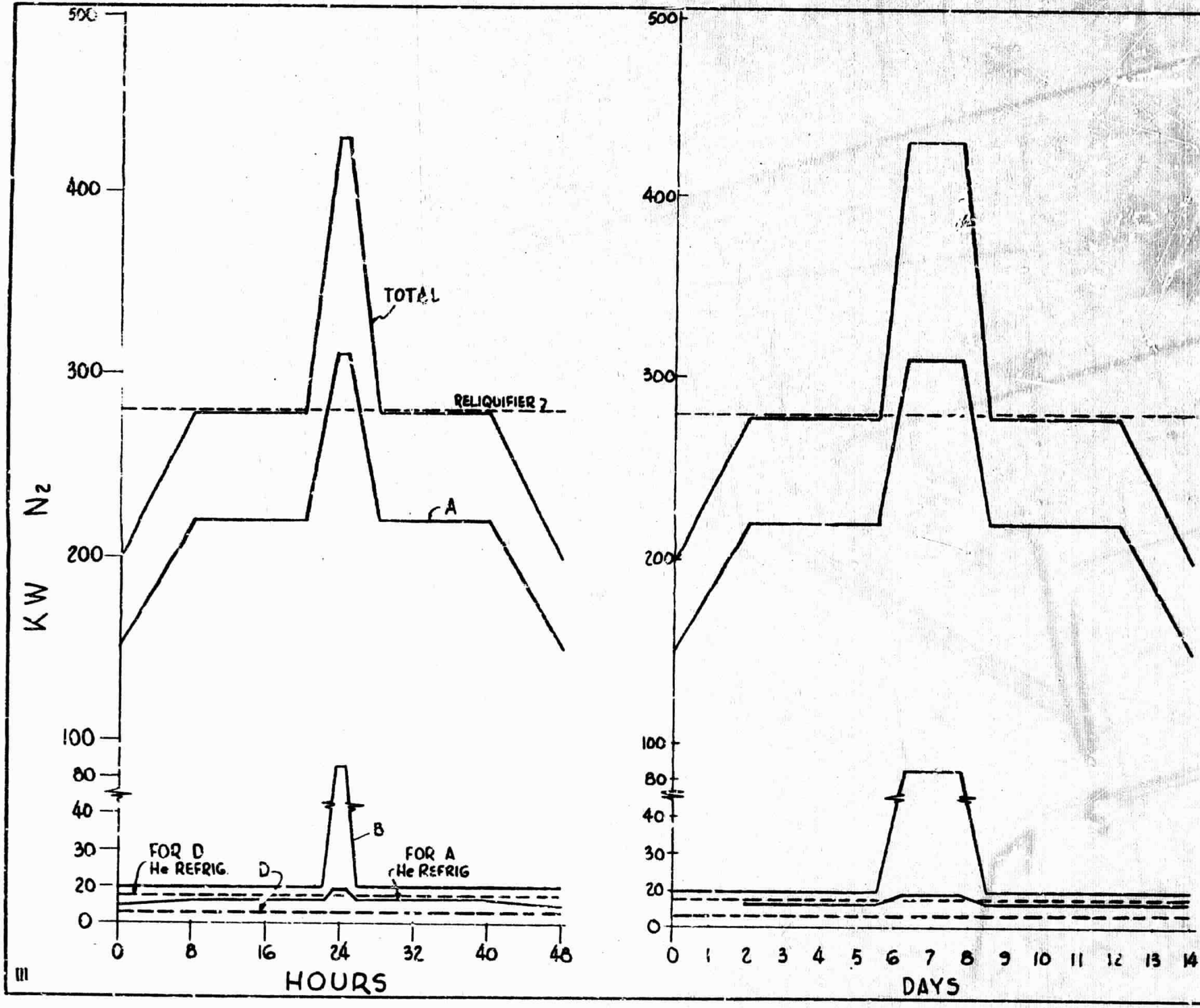
LIQUID HELIUM REFRIGERATION
PLOT PLAN (CHAMBER -D)

JOB No 4185

REV.

FIG. IV-4

III



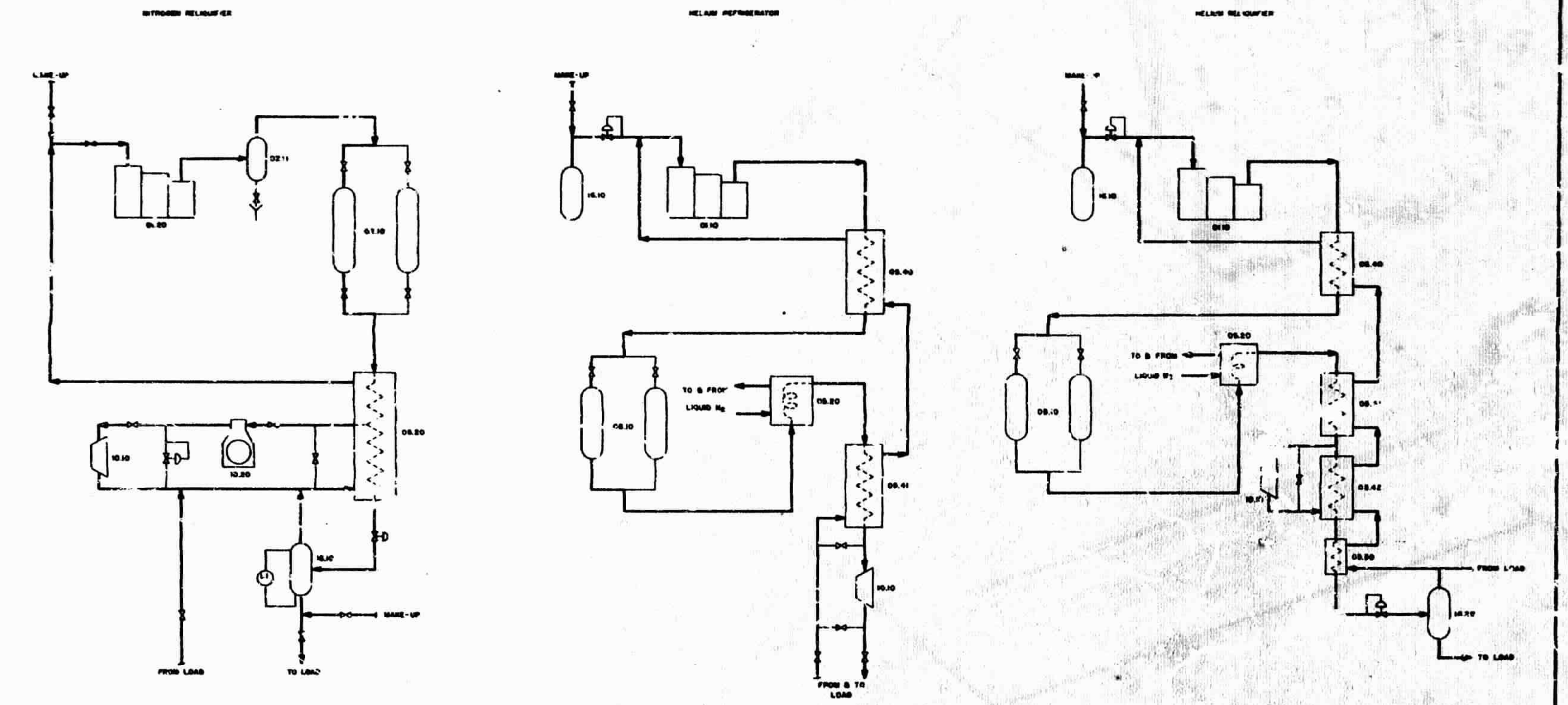
AIR PRODUCTS AND CHEMICALS, INC.
ALLENTOWN, PENN.

NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

NITROGEN USE PATTERN

4185 FIG V-1

111



01.10 NITROGEN COMPRESSOR
01.20 NITROGEN COMPRESSOR
02.10 OIL ABSORBER
02.11 OIL TRAP
05.20 HEAT EXCHANGER
10.10 NITROGEN EXPANDER
10.20 NITROGEN EXPANDER
16.10 FLASH TANK

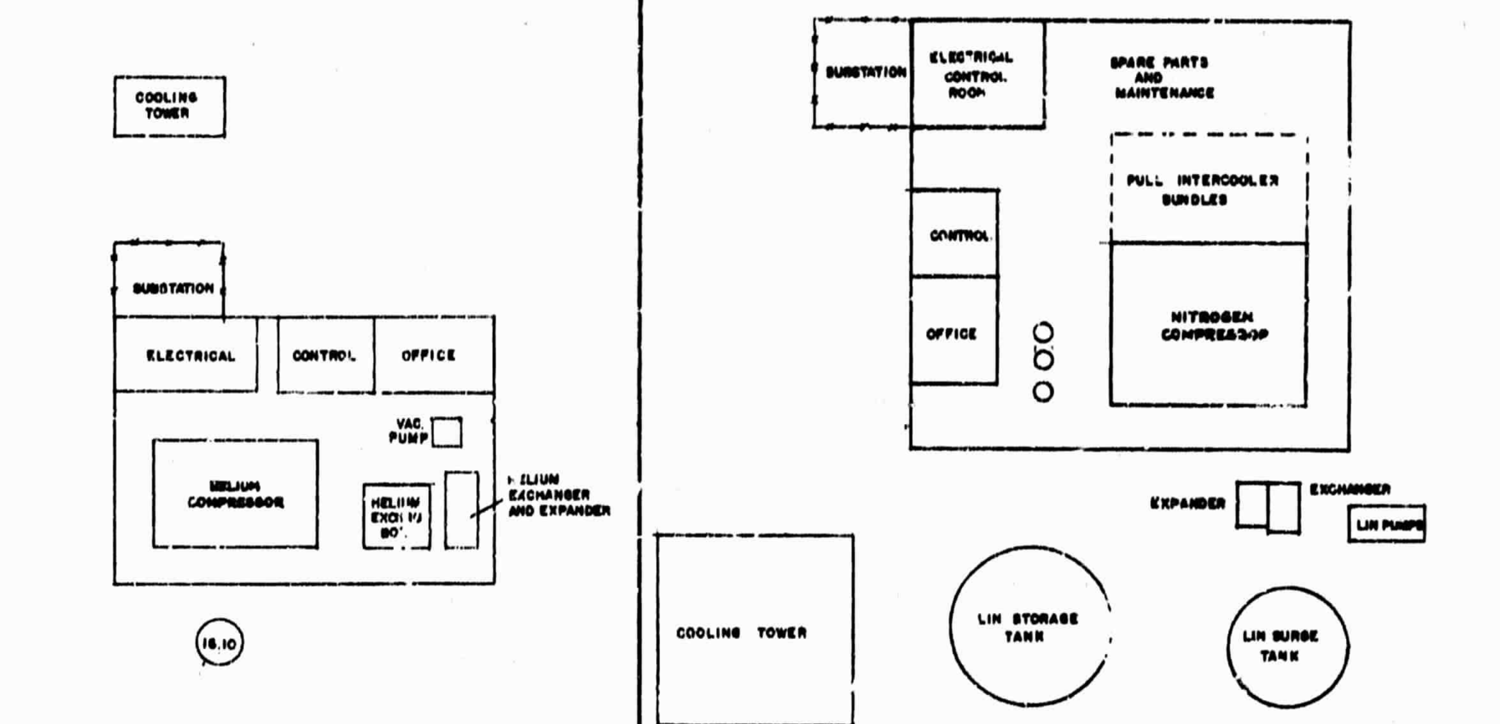
01.10 HELIUM COMPRESSOR
05.20 NITROGEN EVAPORATOR
05.40 HEAT EXCHANGER
05.41 HEAT EXCHANGER
06.10 ABSORBER
10.10 HELIUM EXPANDER
16.10 SURGE TANK

01.10 HELIUM COMPRESSOR
05.20 NITROGEN EVAPORATOR
05.40 HEAT EXCHANGER
05.41 HEAT EXCHANGER
05.42 HEAT EXCHANGER
05.50 SUBCOOLER
06.10 ABSORBER
10.10 HELIUM EXPANDER
16.10 SURGE TANK
16.20 FLASH TANK

AIR PRODUCTS AND CHEMICALS, INC.
ALLENTOWN, PENN.

SCHEMATIC FLOW DIAGRAM
REFRIGERATION

4185 FIG V-2



SCALE 1" = 20'

DENSE GAS HELIUM REFRIGERATION PLANT

NITROGEN RELIQUEFACTION PLANT

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT Nº NAS - 9 - 419

REFRIGERATION PLANT PLOT PLANS

BECHTEL CORPORATION
POWER AND INDUSTRIAL DIVISION

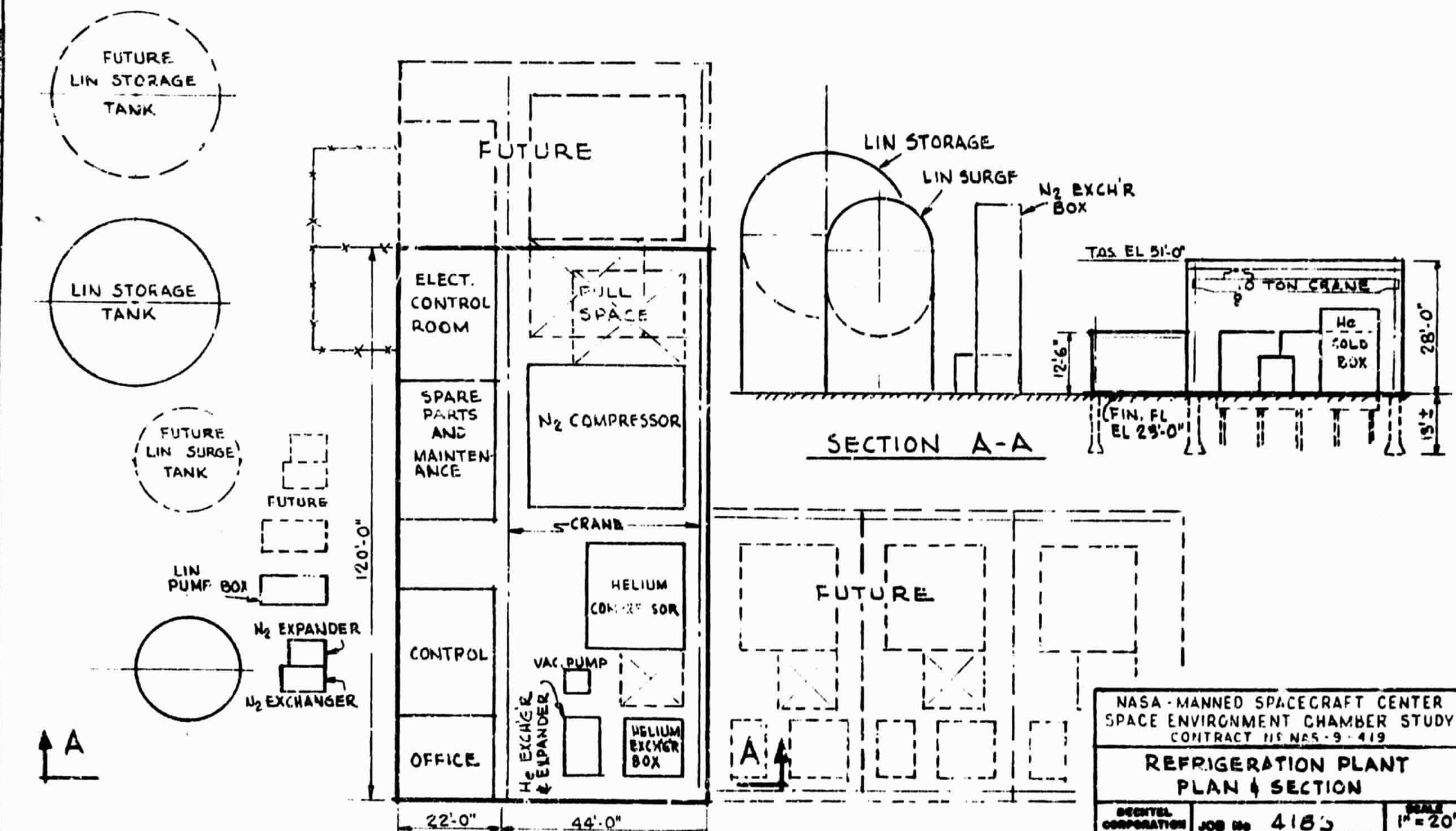
JOB No 4185

DWG NO FIG. V-3

SCALE

REVISIONS

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	INIT.	APPROVALS	DATE
0								



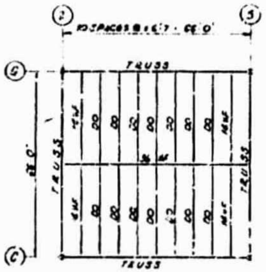
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
CONTRACT NAS-9-419

REFRIGERATION PLANT
PLAN & SECTION

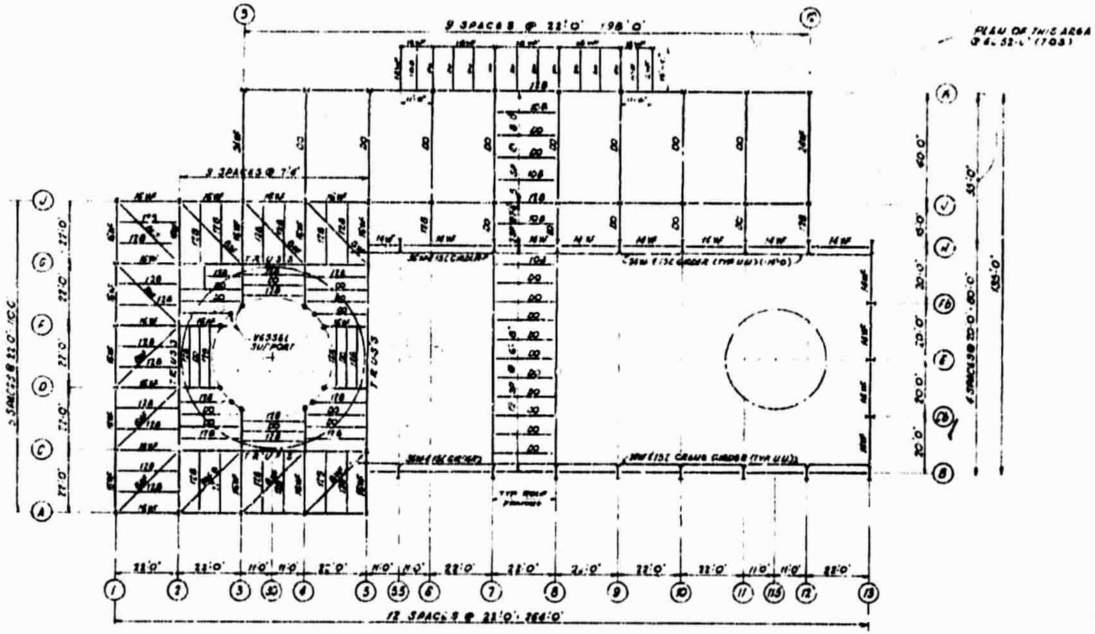
BECHTEL CORPORATION	JOB No 4183	SCALE 1" = 20'
POWER AND INDUSTRIAL DIVISION	DWG NO FIG. V-4	REVISION

REV.	DESCRIPTION	ENG	DR	CHK	SUPV	MAT'L	APPROVALS	DATE
0								

III



PLAN @ ELEV 140'0"



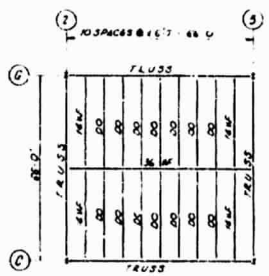
PLAN OF MAIN ROOF @ ELEV 110'0"

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

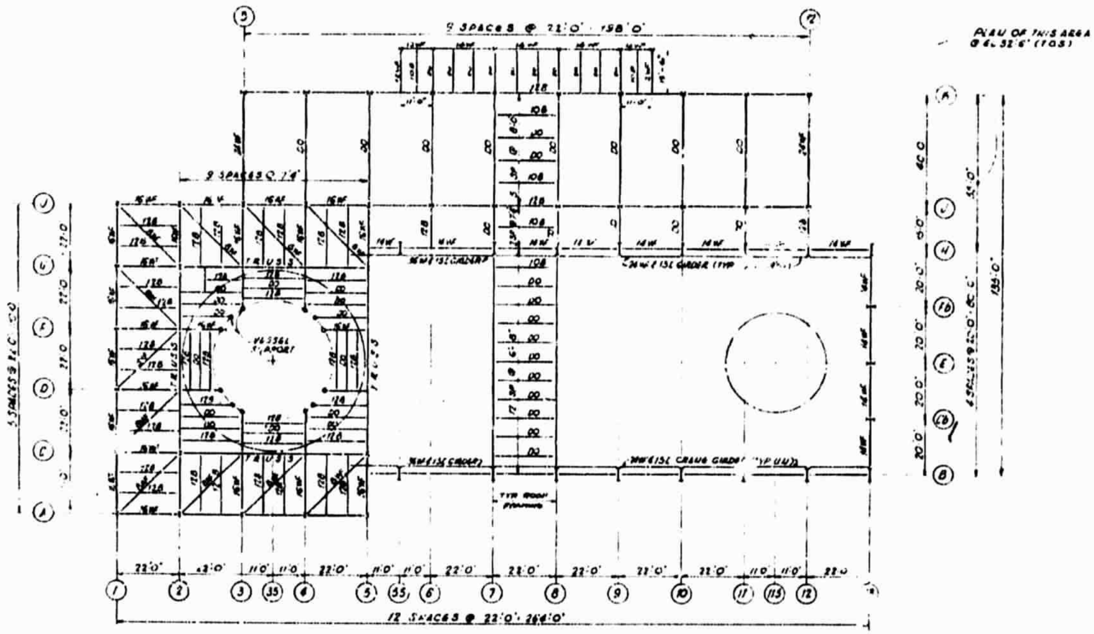
STRUCTURAL STEEL FRAMING PLANS

4185 | FIG VI-1

III



PLAN @ ELEV 140'-0"



PLAN OF MAIN ROOF @ ELEV. 110'-0"

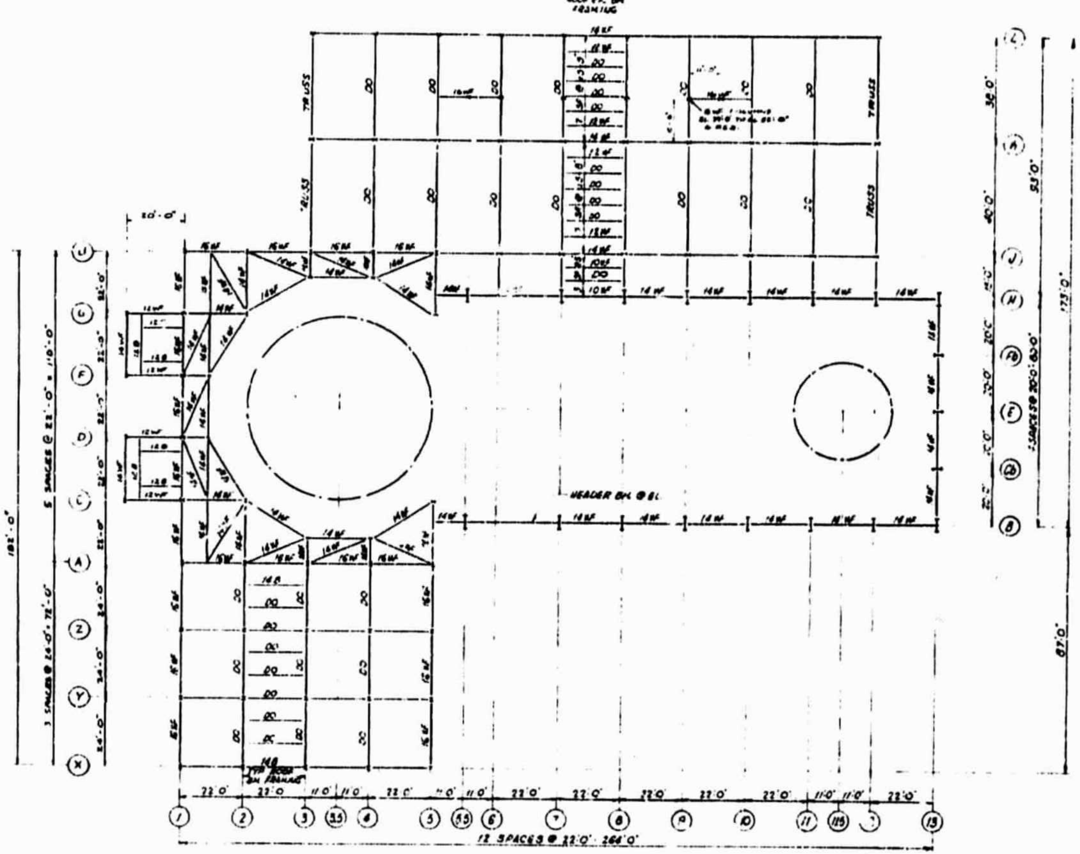
BECHTEL CORPORATION

NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

STRUCTURAL STEEL FRAMING PLANS

4185 | FIG VII-1

III



PLAN AT CONTROL ROOM FLOOR ELEV. 40'0"

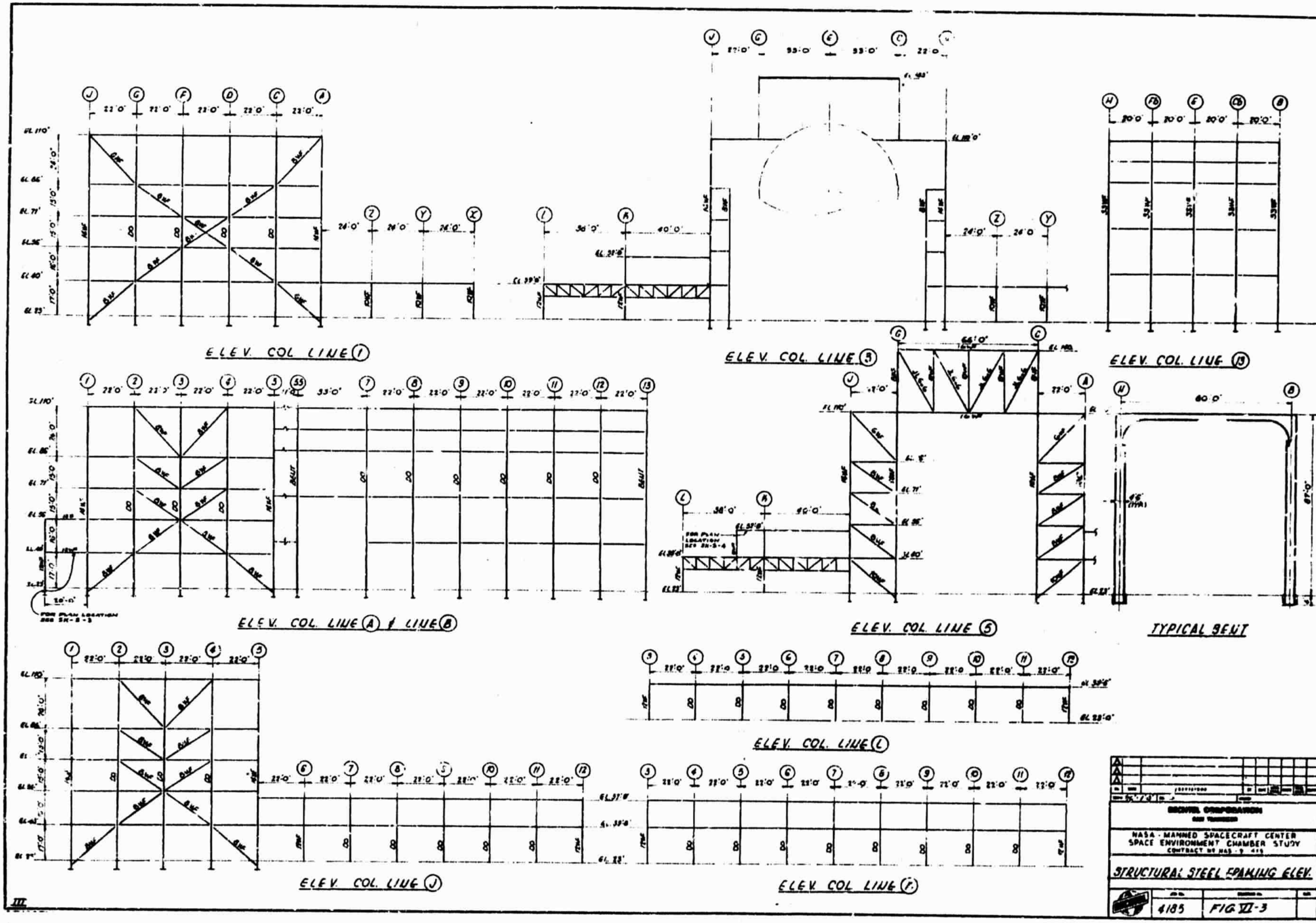
BECHTEL CORPORATION
SAN FRANCISCO

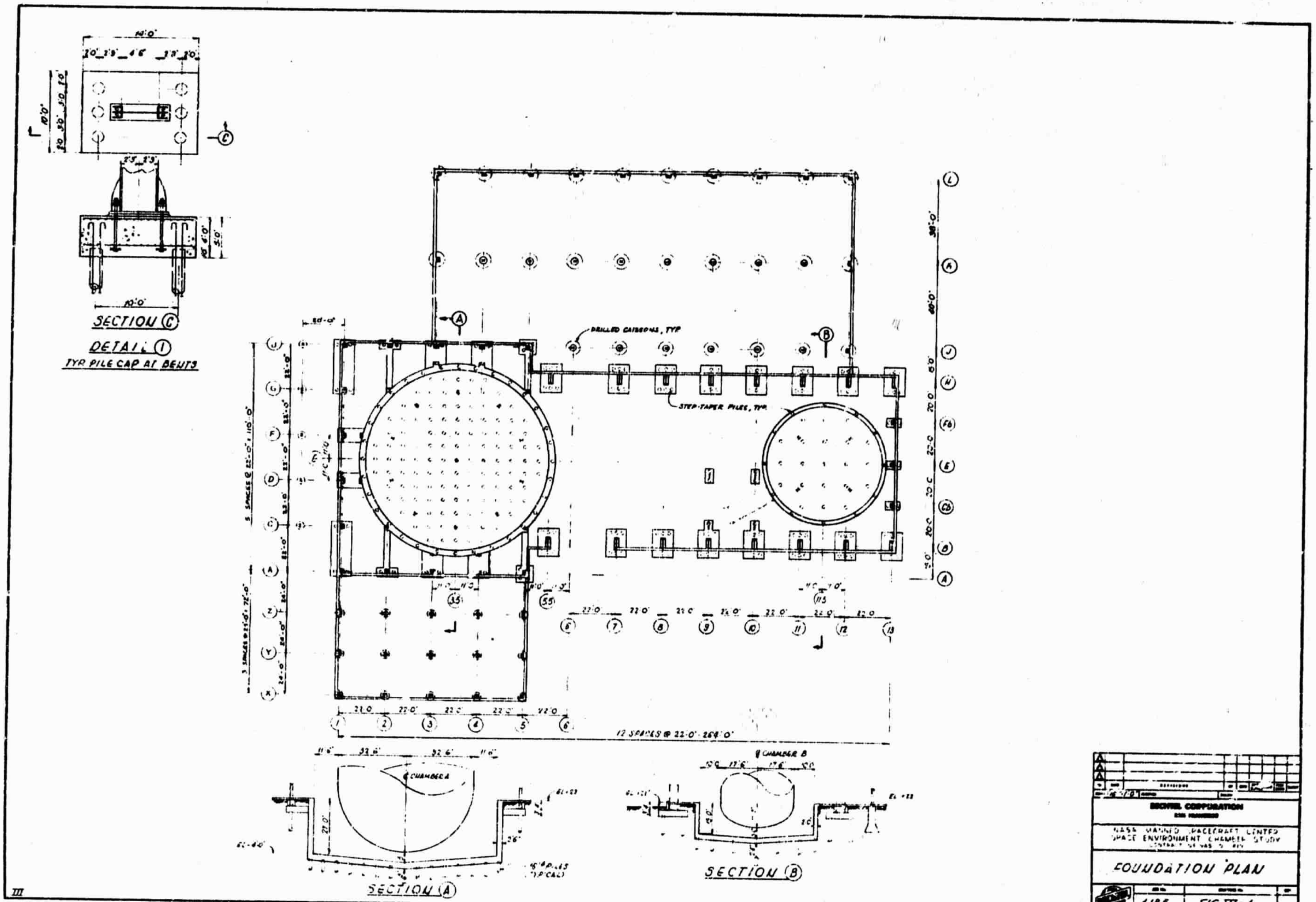
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

STRUCTURAL STEEL FRAMING PLANS

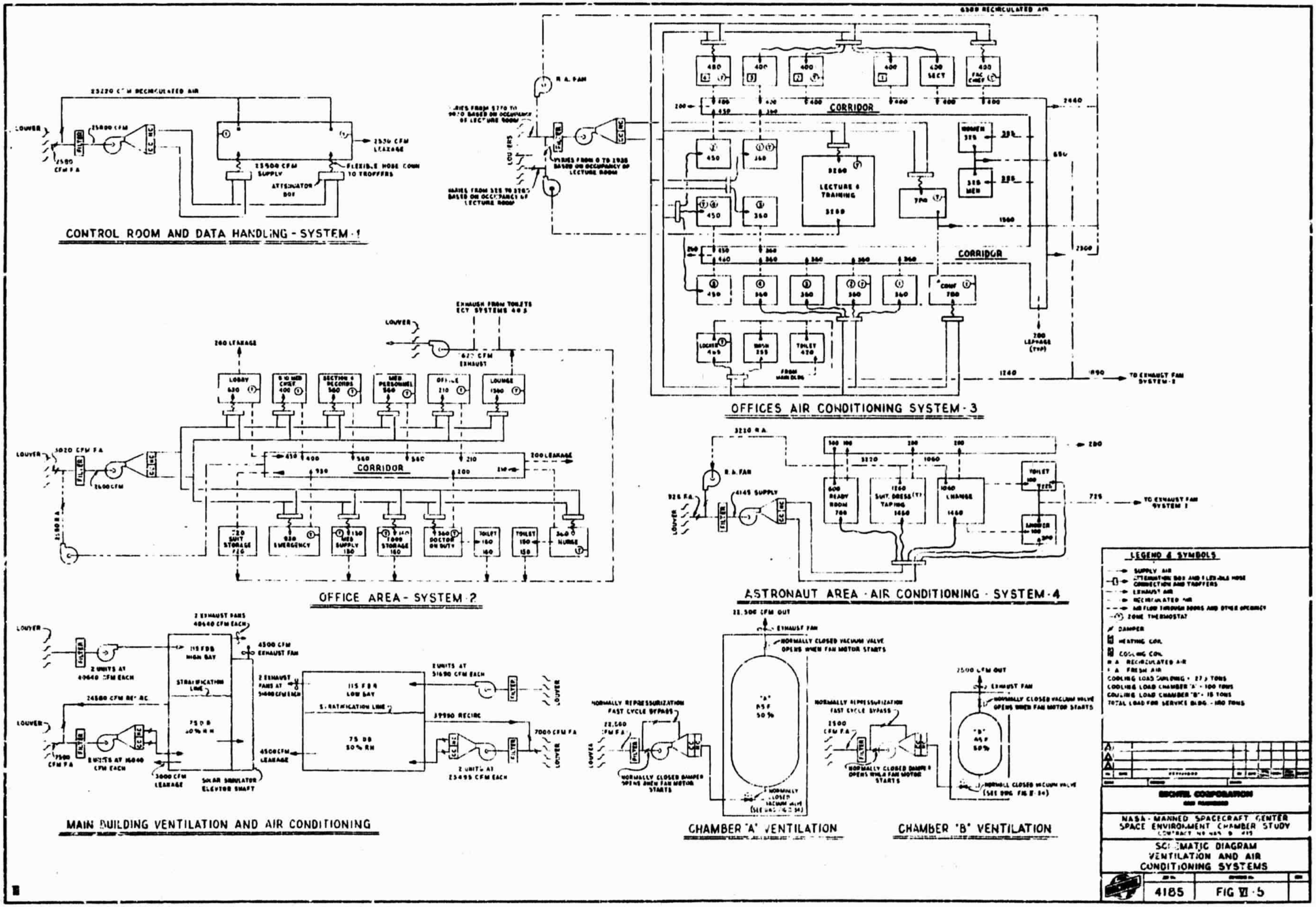
4185 FIG VI-2

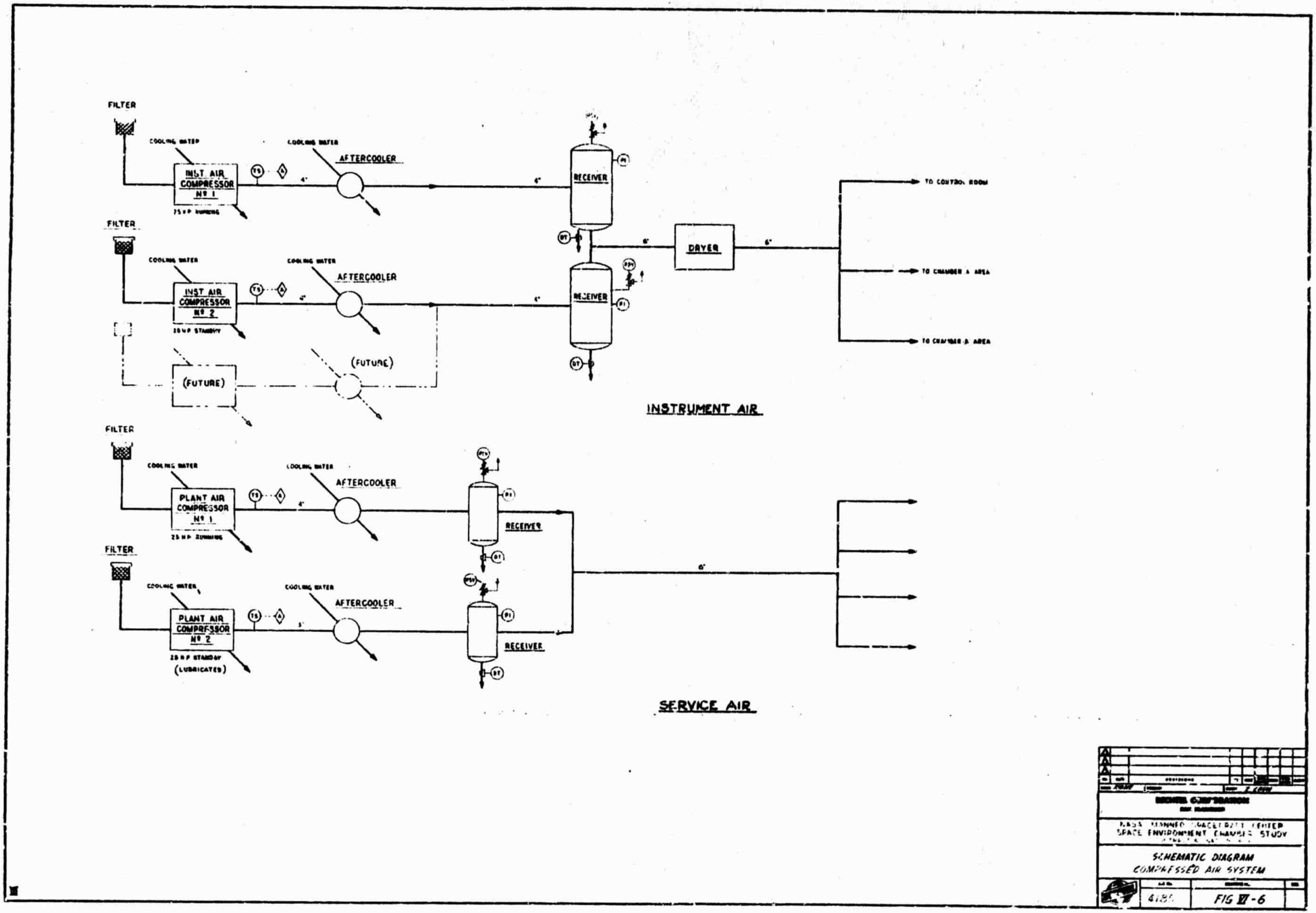
III

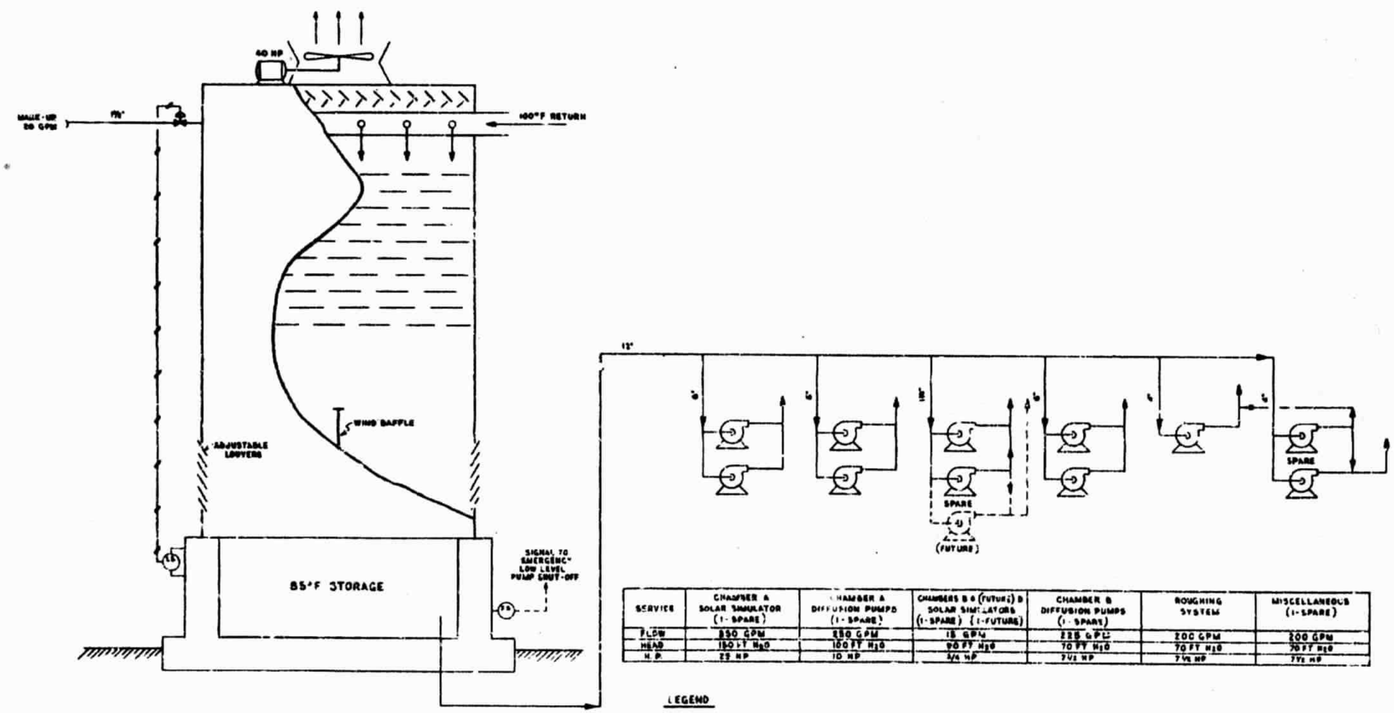

ELEV. COL LINE (1)
ELEV. COL. LINE (3)
ELEV. COL. LINE (13)
ELEV. COL. LINE (A) & LINE (B)
ELEV. COL. LINE (5)
TYPICAL BENT
ELEV. COL. LINE (L)
ELEV. COL. LINE (J)
ELEV. COL LINE (F)
BECHTEL CORPORATION
SAN FRANCISCO
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
STRUCTURAL STEEL FRAMING ELEV.
4185
FIG VI-3
III


SECTION (C)
DETAIL (1)
TYP PILE CAP AT BENTS
DRILLED CAISSONS, TYP
STEP-TAPER PILES, TYP
12 SPACES @ 22'-0" = 264'-0"
5 SPACES @ 22'-0" = 110'-0"
3 SPACES @ 24'-0" = 72'-0"
CHAMBER A
CHAMBER B
SECTION (A)
SECTION (B)
BECHTEL CORPORATION
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
FOUNDATION PLAN
4185
FIG. VI-4

III


CONTROL ROOM AND DATA HANDLING - SYSTEM 1
OFFICES AIR CONDITIONING SYSTEM - 3
OFFICE AREA - SYSTEM 2
ASTRONAUT AREA - AIR CONDITIONING - SYSTEM - 4
MAIN BUILDING VENTILATION AND AIR CONDITIONING
CHAMBER 'A' VENTILATION
CHAMBER 'B' VENTILATION
CORRIDOR
LECTURE & TRAINING
LEGEND & SYMBOLS
SUPPLY AIR
EXHAUST AIR
RECIRCULATED AIR
ZONE THERMOSTAT
DAMPER
HEATING COIL
COOLING COIL
R.A. RECIRCULATED AIR
F.A. FRESH AIR
COOLING LOAD CHAMBER 'A' - 100 TONS
COOLING LOAD CHAMBER 'B' - 18 TONS
TOTAL LOAD FOR SERVICE BLDG. - 180 TONS
BECHTEL CORPORATION
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
SCHEMATIC DIAGRAM
VENTILATION AND AIR
CONDITIONING SYSTEMS
4185
FIG VI - 5


FILTER
COOLING WATER
INST AIR COMPRESSOR Nº 1
25 H P RUNNING
AFTERCOOLER
RECEIVER
TO CONTROL ROOM
DRYER
TO CHAMBER A AREA
TO CHAMBER B AREA
INST AIR COMPRESSOR Nº 2
25 H P STANDBY
(FUTURE)
INSTRUMENT AIR
PLANT AIR COMPRESSOR Nº 1
25 H P RUNNING
PLANT AIR COMPRESSOR Nº 2
25 H P STANDBY
(LUBRICATED)
SERVICE AIR
SCHEMATIC DIAGRAM
COMPRESSED AIR SYSTEM
FIG VI-6

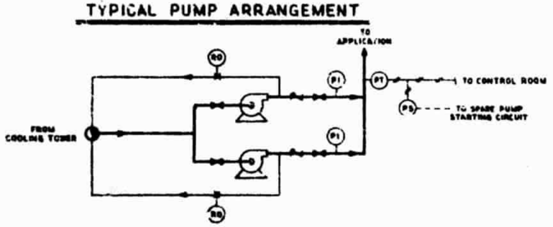


SERVICE	CHAMBER A SOLAR SIMULATOR (1-SPARE)	CHAMBER A DIFFUSION PUMPS (1-SPARE)	CHAMBERS B & (FUTURE) D SOLAR SIMULATORS (1-SPARE) (1-FUTURE)	CHAMBER B DIFFUSION PUMPS (1-SPARE)	ROUGHING SYSTEM	MISCELLANEOUS (1-SPARE)
FLOW	850 GPM	250 GPM	15 GPM	225 GPM	200 GPM	200 GPM
HEAD	150 FT H_2O	100 FT H_2O	90 FT H_2O	70 FT H_2O	70 FT H_2O	70 FT H_2O
H.P.	25 HP	10 HP	3/4 HP	7½ HP	7½ HP	7½ HP

LEGEND

(FI) FLOW INDICATOR
(FS) FLOAT SWITCH
(LS) LEVEL TRANSMITTER
(PI) PRESSURE INDICATOR
(PS) PRESSURE SWITCH
(PT) PRESSURE TRANSMITTER
(RO) RESTRICTION ORIFICE
H.P. CALCULATION BASED ON 75% EFFICIENCY

TYPICAL PUMP ARRANGEMENT

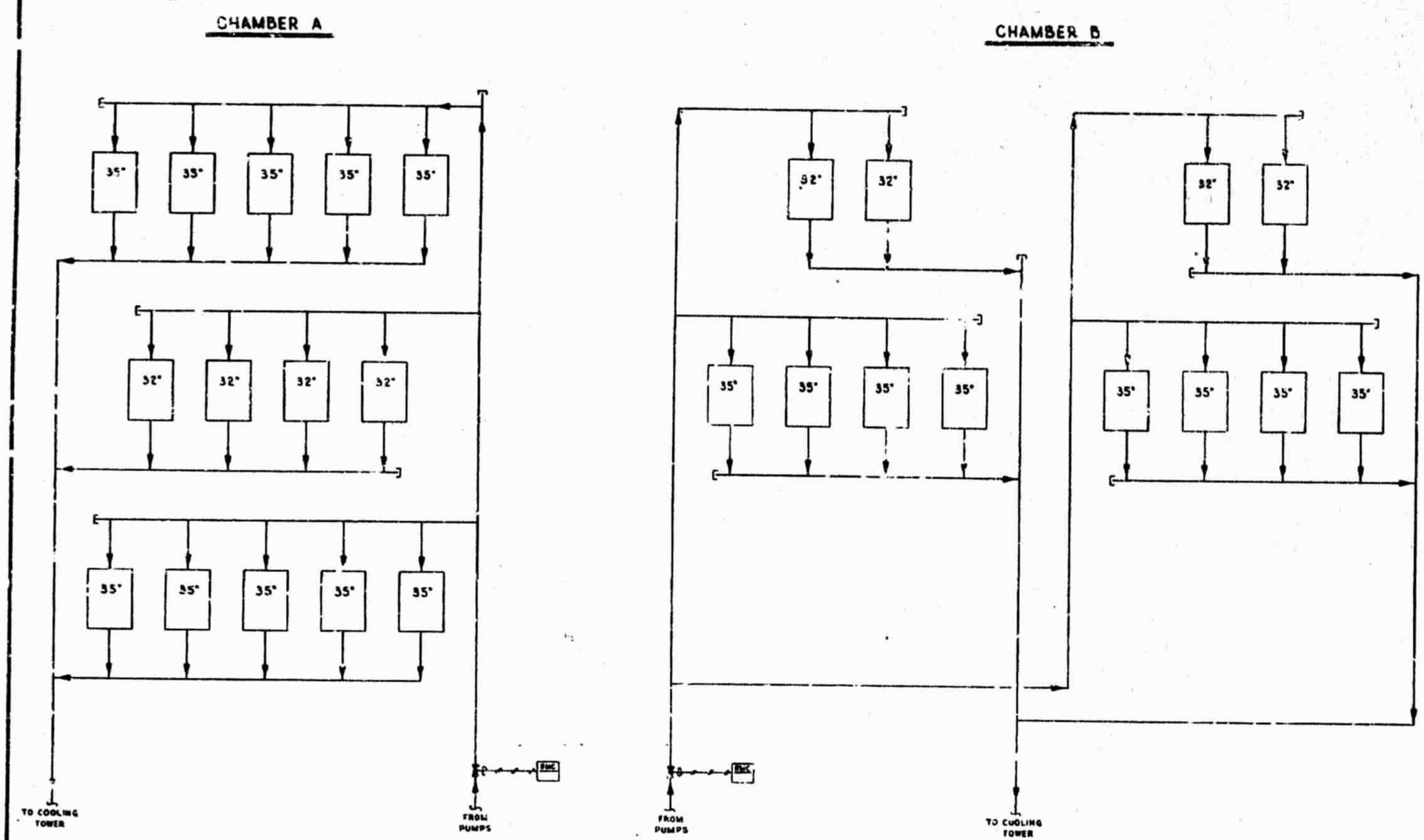


NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

SCHEMATIC DIAGRAM
COOLING WATER SYSTEM

4185 | FIG VI-7

III



BECHTEL CORPORATION

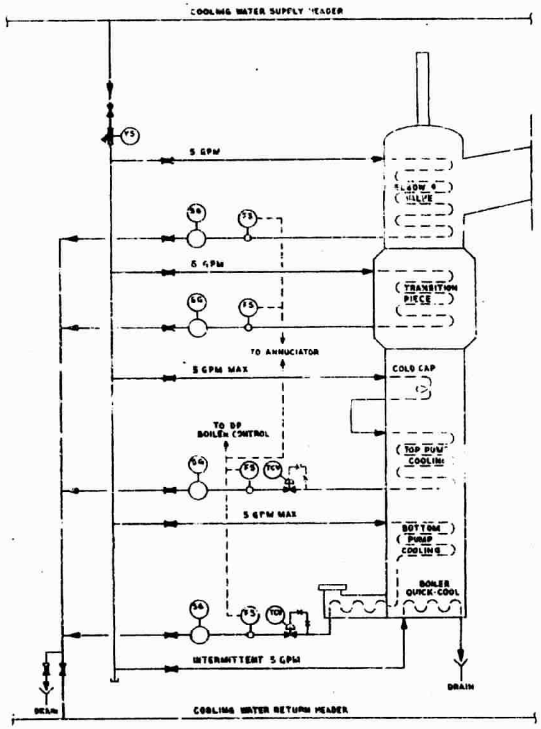
NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

SCHEMATIC DIAGRAM
DIFFUSION PUMPS
COOLING WATER SYSTEM

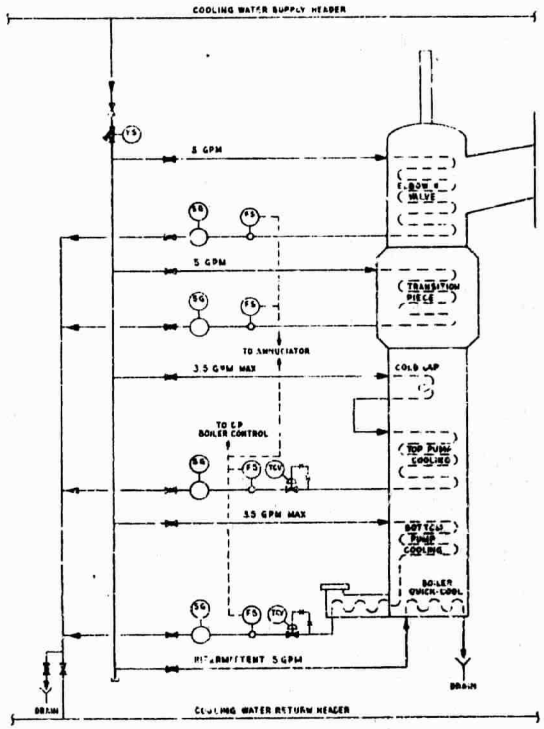
4185

FIG VI - 8

TYPICAL 32" DIFFUSION PUMP STATION



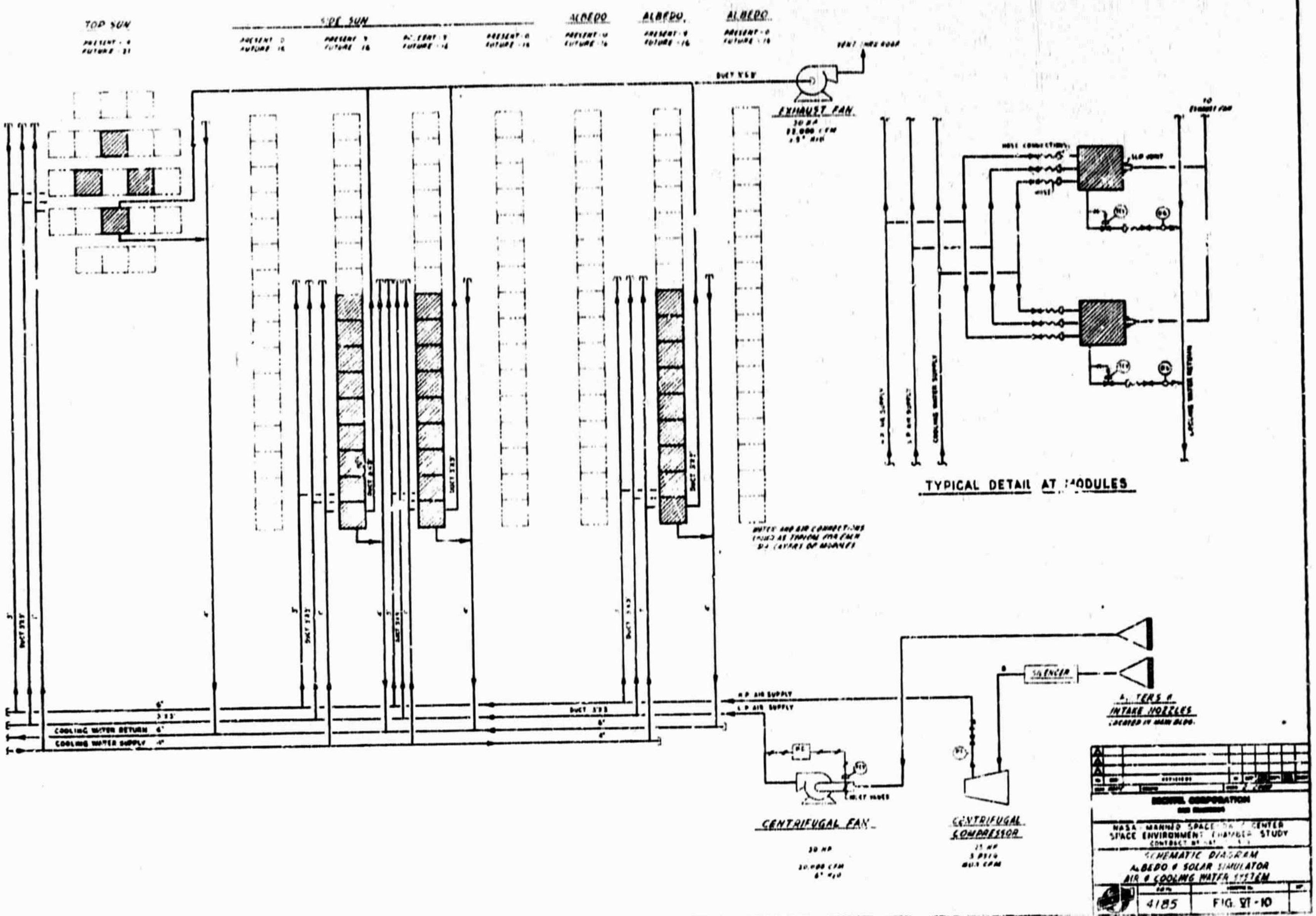
TYPICAL 35" DIFFUSION PUMP STATION



NASA - MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY

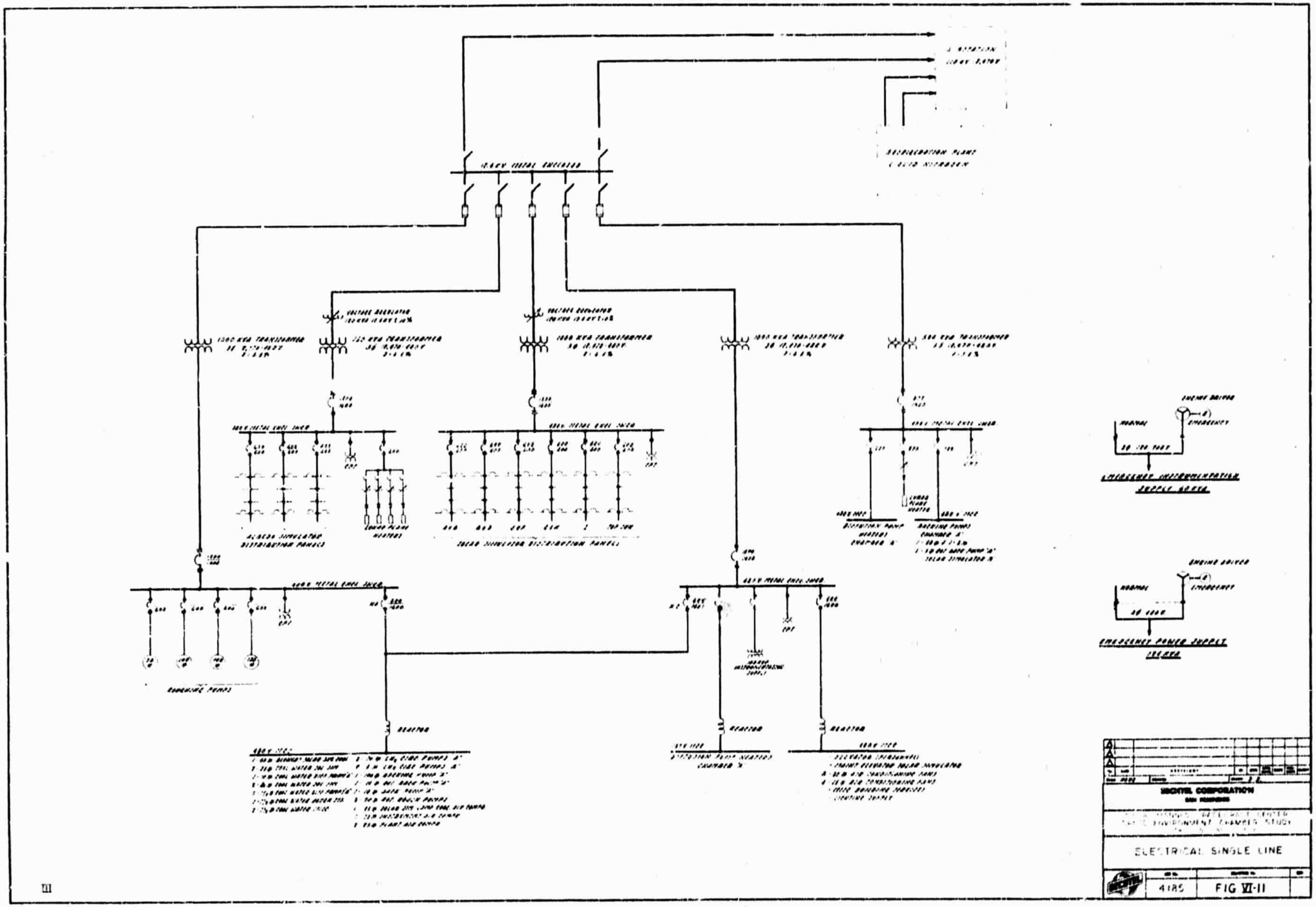
SCHEMATIC DIAGRAM
DIFFUSION PUMP COOLING WATER
TYPICAL PUMP STATIONS SYSTEMS

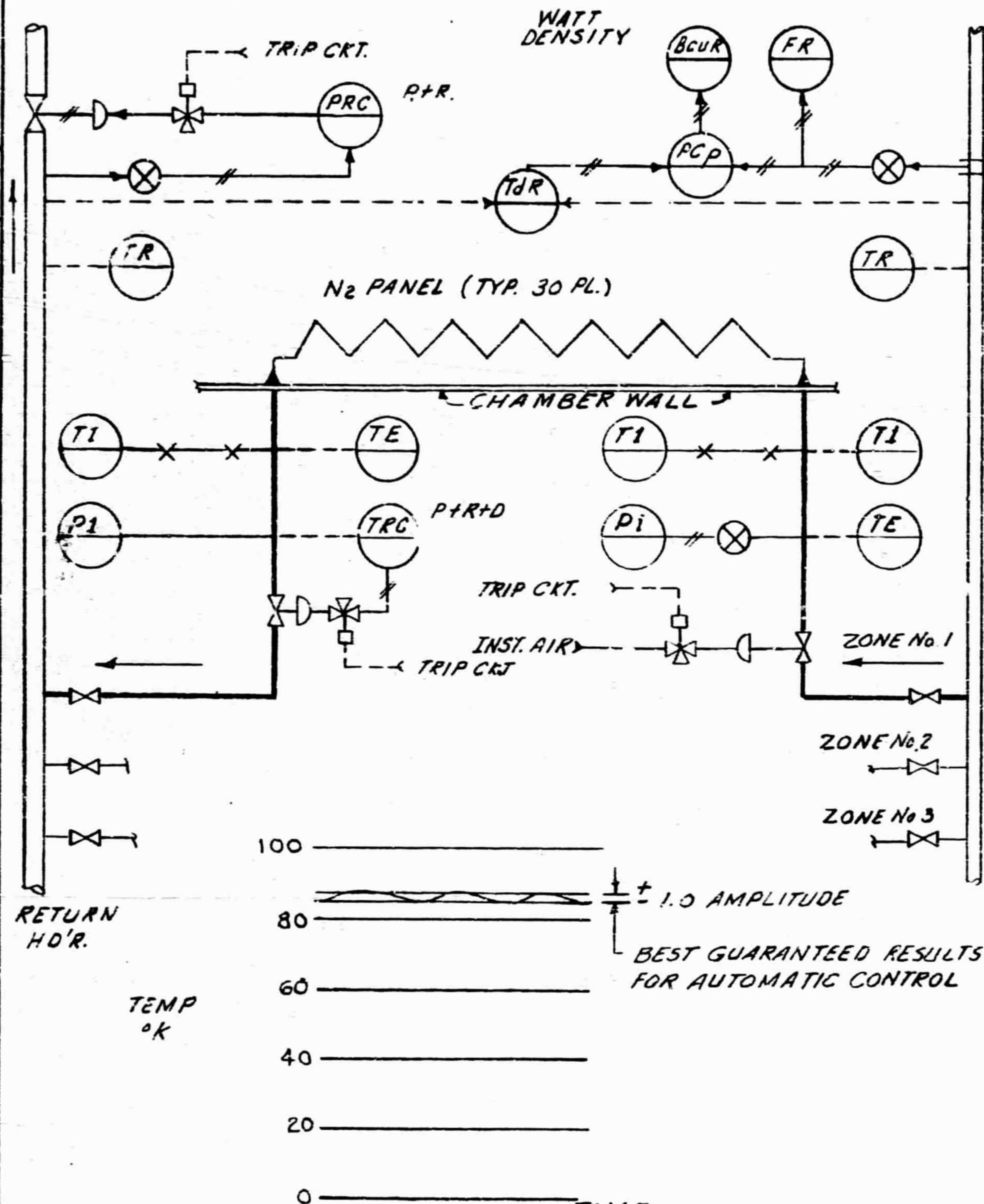
4165 FIG VI-9



TOP SUN
SIDE SUN
ALBEDO
ALBEDO
ALBEDO
EXHAUST FAN
TYPICAL DETAIL AT MODULES
H.P. AIR SUPPLY
L.P. AIR SUPPLY
COOLING WATER RETURN 6"
COOLING WATER SUPPLY 4"
SILENCER
INTAKE NOZZLES
CENTRIFUGAL FAN
CENTRIFUGAL COMPRESSOR
NASA MANNED SPACECRAFT CENTER
SPACE ENVIRONMENT CHAMBER STUDY
SCHEMATIC DIAGRAM
ALBEDO & SOLAR SIMULATOR
AIR & COOLING WATER SYSTEM
4185
FIG. VI-10

III


EMERGENCY INSTRUMENTATION SUPPLY
EMERGENCY POWER SUPPLY
BECHTEL CORPORATION
ELECTRICAL SINGLE LINE
4185
FIG VI-11

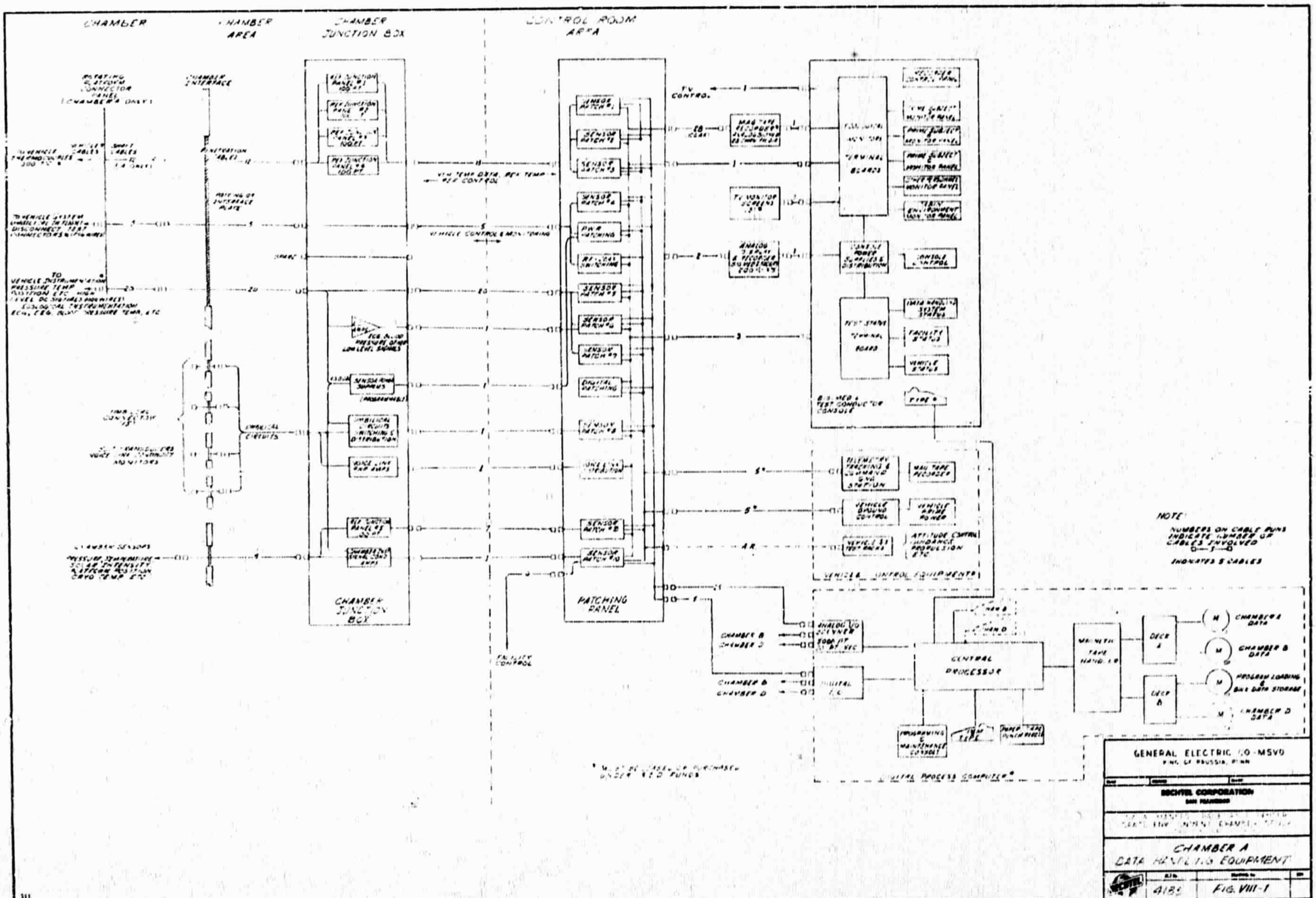


BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT No NAS-9-419	JOB No 4185
	TYPICAL CRYOGENIC CONTROL	FIG VII-1

REV. | DESCRIPTION | ENG | DR | CHK | SUPV | MATL | APPROVALS | DATE

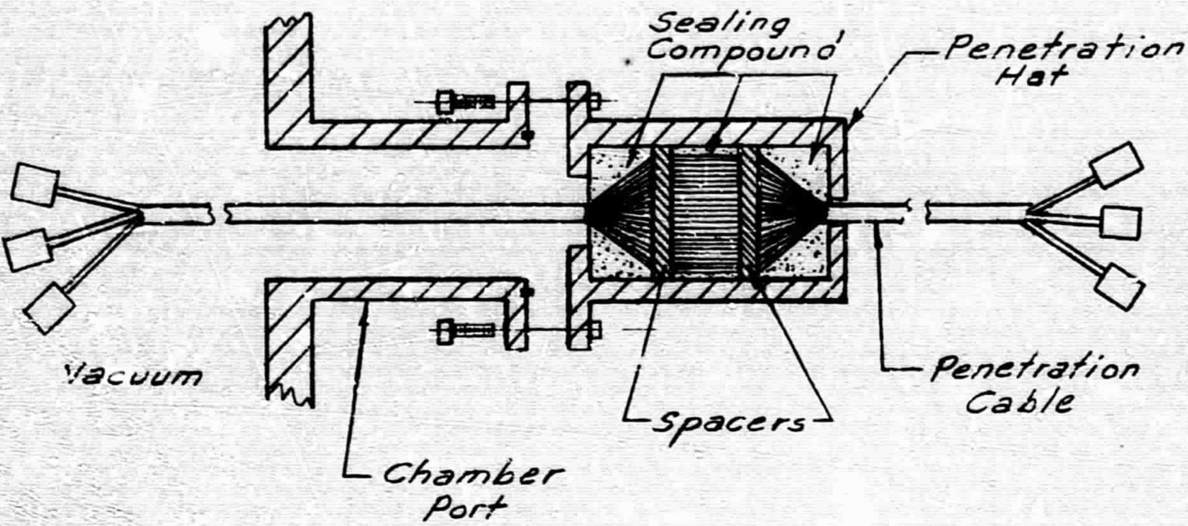
0

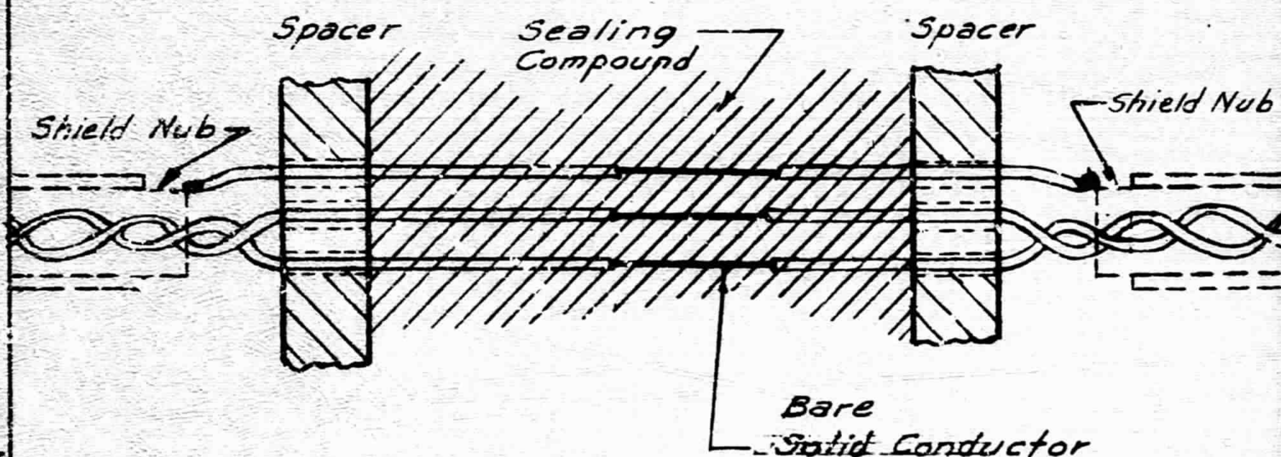
G-231-E 4-14-58 III



CHAMBER
CHAMBER AREA
CHAMBER JUNCTION BOX
CONTROL ROOM AREA
CHAMBER INTERFACE
PENETRATION TABLES
SPARE
UMBILICAL CIRCUITS
CHAMBER SENSORS
CHAMBER JUNCTION BOX
PATCHING PANEL
SENSOR PATCH
PWR PATCHING
DIGITAL PATCHING
T.V. CONTROL
TV MONITOR SCREENS
FACILITY STATUS
VEHICLE STATUS
CONSOLE CONTROL
VEHICLE GROUND CONTROL
VEHICLE PRIME POWER
MAG TAPE RECORDER
VEHICLE & CONTROL EQUIPMENT
FACILITY CONTROL
CHAMBER B
CHAMBER D
CENTRAL PROCESSOR
MAGNETIC TAPE HANDLER
DECK A
DECK B
CHAMBER A DATA
CHAMBER B DATA
PROGRAM LOADING & BULK DATA STORAGE
CHAMBER D DATA
PROGRAMMING & MAINTENANCE CONSOLE
DIGITAL PROCESS COMPUTER*
NOTE:
NUMBERS ON CABLE RUNS INDICATE NUMBER OF CABLES INVOLVED
INDICATES 5 CABLES
* MUST BE LEASED OR PURCHASED UNDER R&D FUNDS
GENERAL ELECTRIC CO-MSVD
KING OF PRUSSIA, PENN
BECHTEL CORPORATION
SAN FRANCISCO
CHAMBER A
DATA HANDLING EQUIPMENT
4183

FIG. VIII-1





GENERAL ELECTRIC CO. - MSVD

BECHTEL CORPORATION POWER AND INDUSTRIAL DIVISION	NASA - MANNED SPACECRAFT CENTER SPACE ENVIRONMENT CHAMBER STUDY CONTRACT Nº NAS - 9 - 419	JOB No 4185	REV.
	INSTRUMENTATION CHAMBER PENETRATION HAT	FIG. VIII - 2	